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SCHOOL OF
BIOLOGY

SCHOOL OF BIOLOGY

BY

CURT THESING

M.D.

Author of " Genealogy of Love "

With 91 *Illustrations and* 1 *Table*

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TO
MY DEAR WIFE
AND
FAITHFUL COLLABORATOR
MARGOT THESING

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PREFACE

THOUGHT is self-communing, a dialogue with oneself. For the most part, we think in question and answer. Nothing elucidates a problem so much as when one has the luck to discuss it with a sympathetic and well-informed friend, when one has to answer objections or to revise one's own views. That is why I have penned the present work in dialogue.

To many, the title I have chosen may seem pretentious, for within such narrow limits only a few parts of the vast science of life can be considered. Another reason for hesitation in adopting my title was that it may seem to challenge comparison with Ostwald's *Schule der Chemie*, a masterpiece of popularisation. But I overcame my diffidence for personal reasons, because the impetus that led me to write my book was the outcome of a long conversation with Ostwald which took place more than twenty years ago. Still, the two books differ much in conception and execution. Ostwald's *Schule der Chemie* is an eminently readable textbook; my *School of Biology* is, rather, a work of entertainment; light literature, which aims simultaneously at imparting information—a sort of biological *Reading without Tears*. It is not a systematic exposition. Often I deliberately cut the thread of my discourse, as must every populariser who wishes to avoid the risk of boring his audience. Still, I cling to my leading ideas, continually resuming the red thread after it has been severed. Besides, my aim has not been to communicate a mass of facts, but to help my readers to think biologically. Above all, I wanted to hold the scales even, to distinguish between facts and theories, and to be just to outlooks I do not share. Even though biological experts will discover nothing new in it, I am not without hope that they will find the book stimulating.

I wish to tender my best thanks to my publisher, Dr. Heinrich Beck, for the cordial sympathy he has shown me in my work, and for the admirable way in which he has produced it. I must also express my gratitude to my wife Margot Thesing, who, by her " I don't understand ", has often nettled me—and incited me to formulate my thought more simply and clearly.

CURT THESING.

BICHL, UPPER BAVARIA,
May, 1934.

FIRST EVENING

THE ORIGIN OF WORLDS

A.—You want to know how life originated ? Whether the Darwinian Theory has held its ground ? Whether acquired characters are transmitted by inheritance ? What importance must be attached to racial biology ? Whether it is possible to determine at will the sex of our offspring ? What part hormones play in our life-mechanism ? Whether death is inevitable, or whether on the other hand personal immortality is conceivable ?—You have asked me a great many questions almost in one breath. It would take me a long time to answer them even cursorily, and I think I should soon tire you. Biology has made great advances and has undergone profound transformations during the last few decades. What you want to know impinges upon some of the most difficult problems of the science of life. Some of these problems are still topics of dispute. In a casual talk I can give you no more than superficial answers.

B.—You cannot scare me away. For several years I have been deeply interested in such questions, and have done my best to follow the progress of biology. But the writings of experts are rendered almost unintelligible by the use of a highly technical terminology, whereas the popularisers write so dogmatically that I never know whether they are presenting disputed theories as accepted facts. Would it not be a good thing if you were to devote the evenings of our vacation to giving me a concise account of the present achievements of the science of life ? Provided only that you will not be vexed with me when I ask foolish questions !

A.—Ask anything you like ; only you, on your side, must not be surprised if, often enough, I can only reply, " I don't know," or that there is no consensus of opinion upon the matter in hand. Though much progress has been made, we are still only in the outer courts of knowledge. Very many enigmas remain to be solved, and the unsolved ones are among the most fundamental. What do you want me to tell you first ?

SPONTANEOUS GENERATION OR CREATION ?

B.—The origin of life !

A.—That is one of the questions which I can only answer by saying, " We don't know."

B.—But surely a science must, at the outset, form some notion as to the origin of the material it is studying ?

A.—I agree. There can be no biologist who has not cudgelled his brains about the origin of life, and has never formulated hypotheses upon the subject. Still, I can only repeat, " We don't know " ; and in this respect we are worse off than the scientists and philosophers of previous centuries, to whom the problem of the origin of life presented no difficulties. In every field of study you can make the same observation, that, as soon as riddles are solved, new crops of riddles spring up in their places. Much that seemed assured fact to the investigators of one generation, becomes falsehood to or is at any rate regarded as disputable by their successors. Biology, which takes man as one of its objects of study, is in a peculiarly unfortunate position. The ultimate basis of any phenomenon is the consciousness of the observer, and it is therefore incumbent upon consciousness to ascertain what consciousness is and whence it derives. Here, you see, we are tending to enter a vicious circle.

B.—But how are we worse off than the investigators of previous centuries, as regards this problem of the origin of life ?

Aristotle

A.—Those earlier investigators did not regard the origin of life as a riddle. They had a dogmatic answer ready-formed in their minds. They either believed that all life was the outcome of a divine creative act, or else they held that animals and plants developed out of inorganic matter by spontaneous generation, being then (perhaps) subject to further evolution. They considered it probable that spontaneous generation was still going on in their own days. Even to Aristotle it seemed self-evident that frogs and other highly organised beings had been generated spontaneously in the marshes where they lived. To us such views are almost incomprehensible, but you must bear in mind that it is little more than two centuries since Leeuwenhoek's improvements in the microscope and the careful investigations he made with this instrument began to throw light upon the intimate structure of the vital mechanism. Only half a century has passed since the discovery of the process of fertilisation upon which the origin of all higher organisms depends.

B.—Yet it still appears to me incomprehensible that such a fantastic notion should find credence. Everyday observation shows us that animals and plants are generated by parents of their own species, and grow up to become more or less faithful copies of their progenitors. Surely the simplest logic must convince every one that this is the expression of a general law, and that all living beings are procreated by living beings of like kind ?

Triops Cancriformis

A.—Not so fast ! Not so fast ! The idea of spontaneous generation is not flatly repudiated by modern science, but has been modified, and is now applied to very primitive forms. Apart from this, let me give you an example of how easy it was for people to believe in the spontaneous generation of even highly organised types of animals. There are many parts of Germany where, when the water-meadows are flooded, there appear vast numbers of the crustacean known as

Triops cancriformis. This creature, which when fully grown is a little more than an inch long, is of an unusual shape, not resembling any other extant crabs, but, rather, the long extinct trilobites of the Silurian seas. Since the strange animal crowds the meadows at short notice when (during several dry seasons) it has not been seen for years, a popular superstition has arisen to the effect that the triops are rained down from heaven.

B.—What is the scientific explanation of this remarkable phenomenon ?

A.—A very simple one. Like other crustaceans, triops lays eggs, but throughout long periods of comparative drought these remain undeveloped, buried in the alluvial earth, and capable of growing up into a new generation of adults as soon as the meadows are flooded for a sufficient time.

B.—Yes, I see you were right in telling me not to be too hasty in my judgments. Since our planet was originally in a fiery-hot molten state, life could not appear on it until it had cooled down enough for living matter to exist. Obviously, then, if we reject the hypothesis of special creation by divine power, the appearance of life on the earth must have been due to spontaneous generation.

ETERNITY OF LIFE

A.—Once more you go too fast. Life may have found its way to the planet Terra from some other heavenly body. Very simple living matter, perhaps, to undergo further evolution here. But I should like to give you another example to excuse the mistake made by earlier investigators who thought that highly organised creatures could be spontaneously generated. These predecessors of ours were no less sharp-witted than ourselves, but they lacked knowledge of the overwhelming quantity of data which collective investigation has placed at our disposal. Even the most illiterate among Europeans know to-day the part the father plays in the procreation of children. But this knowledge was only achieved at a fairly high level of civilisation. For instance, the physiological relationships between the sexual act, impregnation, and birth are unknown to most of the South Sea islanders and to many other primitives. In the South Seas, therefore, the father is not accounted a blood-relative of his children.

FATHERS AND CHILDREN

VIEWS OF SAVAGES

B.—That seems to me almost incredible. Surely, even in the South Seas the natives must see plainly enough that a girl is never with child unless she has cohabited with a man. They must be familiar too with the like sequence of events in the case of their domesticated animals.

A.—You leave out of the reckoning that several months pass after the act of fruitful intercourse before the woman is manifestly with child. Owing to the length of the interval, the assumption of a causal relationship is not so simple as you imagine. Nor is every act of intercourse followed by impregnation. Furthermore, direct observation of some of their domesticated animals convinces the South Sea islanders that the males have nothing to do with the matter.

B.—You puzzle me. Please explain.

Wild Boars

A.—Among many of the Melanesians, the boars are castrated very soon after birth. Since these barrow-pigs neither form spermatozoa nor take any sexual interest in the sows, they procreate no offspring. Nonetheless the sows farrow in the usual way, and the natives not unnaturally regard this as proof that the males have nothing to do with the occurrence of pregnancy.

B.—But how can the sows have young if there has been no sexual act ?

A.—I did not say that there had been no sexual act, but only that the tame boars were all gelded. This is where the " catch " comes in. The indigenes give their sows the free run of the bush, where the females are covered by wild boars.

Invention of the Microscope

B.—No doubt, however, these crude applications of the notion of spontaneous generation were speedily dispersed by the invention and perfectionment of the microscope ?

A.—Wrong again, I'm afraid. It was the other way about, for the doctrine of spontaneous generation was at first, to all seeming, confirmed by microscopy. Easy to understand ! If you examine a drop of fresh, pure water under the microscope, you will not, to begin with, discover in it any trace of life ; but within a few hours or days the drop will be swarming with live creatures, though lowly organised ones. Until the developmental history of these living beings was known, there was no other way of accounting for them except as the products of spontaneous generation. Thus a few decades back it was, so to say, an article of biological faith that these " infusoria ", as they were called because they appeared " from nowhere " in infusions of hay or leaves, were products of spontaneous generation ; and that bacteria originated of themselves in putrefying flesh. It was held, in fact, that carrion made micro-organisms, and not that micro-organisms made carrion.

Infusoria

Pasteurisation Experiments

It was Pasteur's work that first freed people's minds from these views which now seem to us childish. The processes of " pasteurisation " have become familiar to every one, and Pasteur's name has been immortalised in current speech.

B.—You are speaking of the preservation of milk and other putrescible articles of food by heating them for a considerable period at a fixed temperature ?

A.—Yes, Pasteur's experiments showed that when tins containing meat or glass vessels holding hay infusion were heated long enough to destroy any living germs they might contain, and when the access of contaminated air was subsequently prevented, these putrescible substances might be kept for interminable periods without undergoing putrefaction and without the appearance of any microscopic fission-fungi, within the containers. If the process of sterilisation be effected with sufficient care, there is no known limit to the period for which preserved articles of food can remain " fresh ".

B.—But if we open a specimen of canned food, and leave the contents exposed to the air, it soon putrefies. I suppose that is because living germs reach it ?

A.—Of course. But there is an artifice by which we can prevent putrefaction occurring, despite the free access of air.

B.—What is the " artifice " to which you refer ?

A.—The air which gains access to the pasteurised though putrescible material must be freed from all the living germs it contains. You can do this by passing it through a red-hot tube, or through a strong solution of potash, or strong sulphuric acid. Air thus treated will never induce putrefaction in sterilised but putrescible substances, such as meat, for the germs it contains are destroyed before it reaches the meat.

B.—It seems to me there is perhaps a flaw in the argument here. May not the chemical composition of the air be modified by passing it through a red-hot tube or through strong alkalis or acids, and may not these chemical changes lead to the disappearance of some substance that is essential to spontaneous generation ?

A.—There is warrant for your criticism. Air is more or less completely deprived of carbonic acid by passing it through potash solution, and the traces of ammonia in the atmosphere are destroyed by sulphuric acid. Still, we can rid the air of germs by methods which do not alter its chemical composition. You can preserve your sterilised putrescible substance indefinitely in a test-tube that is closed by nothing but a plug of cotton-wool. The cotton-wool does not prevent the free access of air, but serves as a filter by which the germs are arrested. Indeed, fermentation and putrefaction can be prevented in sterilised fermentible or putrescible fluids when these are contained in retorts whose necks are long and fine horizontal tubes sinuously curved. As the temperature varies, air will pass into or out of such retorts, but the germs with other dust particles in the entering air, being heavier, will settle in the lower parts of the curves. Thus the contents of the vessels in question will remain germ-free although air has access to them.

B.—Are these experiments regarded as convincing evidence that there is no such thing as spontaneous generation ?

ACUTE EXANTHEMATA

A.—Yes, as far as the now known bacteria and animalcules are concerned. Of course, had earlier investigators had our present knowledge of the intricate structure of these little creatures, it would never have been supposed that organisms which bear the obvious stamp of an evolution that must have begun many, many millions of years ago could arise spontaneously out of the direct transformation of inorganic matter. Nevertheless, we are not yet acquainted by direct observation with all the minute organisms that exist. Despite manifold improvements in microscopy, the power of our instruments remains limited. We know, by inference, that there must be microbes so small as to escape scrutiny under the strongest magnification as yet obtainable. Let me mention, for example, two of the class of diseases known as acute exanthemata, namely measles and scarlatina. Analogy convinces us that, like anthrax and typhoid, they must be caused by specific organisms, but these organisms have never yet been detected, presumably because they are below the limit of visibility.

B.—Then all that has so far been proved is that no living creatures are spontaneously generated in nutritive substances which have been sterilised and which are safeguarded against the access of germs ? It cannot be regarded as proved that spontaneous generation has never occurred, or that it may not occur to-day under certain (still unknown) conditions ?

A.—I agree. The experiments of Pasteur and his successors have not shown spontaneous generation to be impossible. Indeed, many biologists of note consider the occurrence of spontaneous generation to be a logical inference from the theory of evolution, whose validity is no longer in doubt among serious thinkers.

Artificial Living Creatures

B.—I have even heard that attempts have been made to generate artificial living creatures.

Félix Archimède Pouchet

A.—Such attempts have indeed been made ; notably by the French investigator Pouchet, who had a lively controversy with Pasteur ; but when the supposedly artificial living creatures appeared in the culture media, it was always possible to show that they were fission-fungi or bacteria whose germs had not been excluded with sufficient care. When we come to discuss the histology or minute structure of living matter, you will see for yourself that such experiments are devoid of scientific meaning. As Schopenhauer writes : " When a hypothesis has once entered the head, it carries on there an independent life resembling that of an organism, insofar as it assimilates from the outer world only what is agreeable to and harmonious with itself, while either avoiding or extruding as indigestible whatever it considers disagreeable or heterogeneous." That is why the notion of a parentless generation or even of the artificial production of unicellular organisms is perpetually cropping up in the minds of certain imaginative thinkers.

Schopenhauer

B.—Still, Pouchet was a trained observer. How was it possible for him to make so gross a blunder ?

A.—Please don't forget that the greatest dimension of many micro-organisms does not exceed a thousandth of a millimetre. Some years ago, when for a technical periodical, I was reviewing recent

THE EXCITING CAUSES OF CANCER

publications concerning investigations to discover the exciting causes of cancer, I found that within a brief space of time a round dozen of such alleged exciting causes had been detected, and had been described in full detail. Really, not one of them had anything to do with the causation of the disease; they were not organisms at all, but only artificial inorganic products.

BATHYBIUS HAECKELII

B.—I remember reading in one of Haeckel's books that Huxley, when engaged in deep-sea investigations, discovered a strange organism which had not acquired the cellular type of organisation, and which seemed capable of being continually generated out of inorganic matter on the sea-floor.

A.—You are thinking of the famous or notorious Bathybius Haeckelii. In it you have a typical instance of the way in which even the most distinguished investigators can err.

B.—Then Bathybius Haeckelii was not a living creature at all?

A.—No, for further study showed that what Huxley had regarded as an extremely primitive organism was merely a flocculent precipitate of gypsum thrown down from sea-water by alcohol, and the hypothesis of its organic character was soon abandoned by Huxley himself. Haeckel however, to the day of his death, continued to believe

ORGANISMS WITHOUT ORGANS

that there are "organisms without organs"—living creatures which have not yet attained the level of cellular life. Among such creatures, he reckoned bacteria. This contention, however, has been shown to be erroneous. In actual fact, we do not know of any instance of spontaneous generation; we are not acquainted with any organism so primitive that it might be supposed to have originated by spon-

FLUID CRYSTALS

taneous generation. Even the so-called fluid crystals which in many outward respects remind us of living creatures, creeping from place to place and undergoing fission like protozoa and protophyta, cannot be regarded as preliminary stages of life. The upshot is that the

OMNE VIVUM EX VIVO

old saying "omne vivum ex vivo" still holds the field.

KANT AND LAPLACE

B.—All the same, as far as I know, cosmogonical science continues to accept the theory of Kant and Laplace, according to which the solar system and the planets (our own included) have developed out of molten or gaseous white-hot masses (the nebular hypothesis).

If, then, we reject the miracle of special creation by divine power, how can we avoid assuming spontaneous generation as the natural explanation of the origin of life?

Eddington

A.—Although the nebular hypothesis of Kant and Laplace has in certain respects been modified of late by A. S. Eddington, physicists and astronomers in general are certainly inclined to accept the view that the earth gradually developed out of matter in a white-hot gaseous condition. Eddington's theory, in particular, gives support to the assumption.

Preyer

But before I go into that matter, I should like to give you another example of the way in which human intelligence may at times stray from the right path. In a book published during the eighties of the nineteenth century, *Die Hypothesen über den Ursprung des Lebens*, the well-known physiologist Wilhelm Preyer advanced the opinion that our notion of life is much too narrow. Setting out from Harvey's principle that all living creatures originate from antecedent living creatures, Preyer contended that it was illogical to suppose matters had ever been different. It is a daily observation that plants transform inorganic substances into living matter. In view of this he held it would be far more reasonable to regard living matter as primary, and inorganic matter as a secondary product of organic matter.

Primariness of Living Matter

" If ", writes Preyer, " we cast aside preconceived notions that lead us to suppose that the only living protoplasm which can exist must have the characteristics with which we are familiar, and if we discard what is nothing more than an antiquated prejudice based upon indolent thinking, namely the belief that there was a time when nothing but inorganic matter existed on our planet, we shall not hesitate to go a step farther. We shall cease to think of spontaneous generation as something that happened once for all, and shall recognise the movement we call life to be primary, not secondary." His imagination worked in such a way as to lead him to the belief that the huge white-hot mass of rotating vapour of which our solar system originally consisted was but one gigantic organism. Its movement was the essential manifestation of its life, and it contained within itself the substances which constitute what we now call living matter. Only as the cooling process advanced did the substances which had to consolidate when the temperature fell detach themselves as rigid portions that ceased to participate in the living movement of the whole. They constituted the first inorganic matter. " Not until, in course of time, these substances became consolidated at the surface of the earth, dying out so to say, did the combinations of the hitherto gaseous and liquid elements come into being which by degrees grew more and more akin to protoplasm—the substratum of the life of our own days."

The Concept of Life

B.—Do not Preyer's theories contain a sound kernel? Is it not possible that we dogmatically take an unduly narrow view of life when we associate it indissolubly with protoplasm and the cell?

A.—I will answer that with a rather crude comparison. Every concept, every term, has both intension and extension. The totality of its characteristics comprises the intension; a definite number of kinds or species makes up the extension. The more I restrict the intension, the greater becomes the extension, until the concept or term becomes so general that it is transformed into an empty word which ceases to have any significance for the purposes of limitation or distinction. "For where concepts fail, nothing but a word remains." If I define a chair as "an object intended to be sat upon, having four legs, a seat, and a back", I distinguish between every conceivable chair and every conceivable table. But if, without further restrictions, I content myself with defining a chair as "an object having four legs", I may be referring, not only to a chair, but also to a table, a piano, a dog, etc. Similarly with the term "life". Life is something which presents certain characteristics: first of all, nutrition, respiration, tissue change, and excretion; secondly, the changes in form that manifest themselves as growth, development, and reproduction; thirdly, the transmutation of energy, which takes the form of movement, response to stimuli, the emission of heat, etc. But, as far as our experience goes, these multifarious characteristics are only met with fully associated in a substance to which has been given the name of protoplasm, a substance consisting of extremely unstable organic compounds in colloid solution. Now, in our experience, this protoplasm, when manifesting its vital qualities, only does so in the form of discrete cells. But Preyer extended the concept of life to include everything that moves. This does not explain life, but merely waters down the term until it becomes unmeaning.

Protoplasm

B.—I understand what you are driving at, but what you say about protoplasm and its composition takes me out of my depth.

A.—We will return to that, and consider it at some length. But it will be better, for the moment, to discuss the theories that concern the way in which life has appeared on the earth and has undergone further development there.

Origin of the Solar System

B.—I would rather, at this stage, have an account of the differences between the respective cosmogonical theories of Kant, Laplace, and Eddington.

A.—All right, I will do my best to give you an account of the essentials of these three theories. According to Kant, very long ago the space now occupied by our solar system was filled by a chaotic mass which, influenced by gravitation, condensed upon various nuclei of maximum specific gravity. Round the chief of these nuclei was formed the sun ; round other, smaller nuclei were formed the planets and the moon. Thus, in Kant's view, the earth and the other planets were not formed out of the sun, but are, one might say, the sun's little brothers and sisters. Owing to gravitational condensation, these stellar bodies became white-hot, and, as a further consequence of gravity, the smaller bodies came to circle round the larger ones. Laplace's "nebular hypothesis" was somewhat different. The French astronomer believed that the solar system originated in a rotating cloud or nebula of gaseous matter. As the nebula condensed, its rotatory movement became increasingly rapid. Owing to the consequent intensification of centrifugal force, parts of the periphery were detached from the central mass, continuing to revolve around it, and also to revolve upon their own axes. Thus arose the planets, and, the process repeating itself in their case, they gave birth to their satellites, the moons. Laplace, therefore, regarded the planets and the moons as children and grandchildren of the sun.

Eddington, like Laplace, supposes that the space now occupied by our solar system was originally filled by a tenuous, dark, nebular material which, influenced by gravity, slowly condensed, growing hotter in the process. The central sun thus formed, red-hot to begin with, became white-hot as it contracted, passing into a condition analogous to that of Sirius to-day. Its inner temperature must have been one of several million degrees Centigrade. Owing to the intensity of the heat, the various chemical compounds were disintegrated, with the result that there was a wild confusion of etheric undulations, atomic nuclei, and electrons in the interior of the giant star. Now

RADIATION PRESSURE

we know that light exerts a radiation pressure which rapidly increases with the increase of temperature. The radiation pressure arising in the interior of the sun in consequence of the transformation of matter into radiations created a powerful centrifugal current of energy propagating itself in all directions throughout the universe. Inasmuch, however, as the radiation pressure intensifies proportionally with the temperature, a limit is imposed upon increase of temperature, for a point must ultimately be reached when the sun will be disintegrated. On the other hand by the unceasing dispersal of heat into outer space (which is extremely cold), such a white-hot star, in the course of a period measurable only in thousands of millions of years, while continuing to shrink, passes through yellow-hot and red-hot stages into a terminal phase of cold. It is then an extinct star, which has ceased to emit light radiations, and discloses its presence through the force of gravity alone (or through eclipsing adjacent stars).

B.—But how, upon this theory, did our world and the other planets come into being ?

A.—As it were through a traffic disaster, or, to put the matter more aptly, through an explosion. Another star approached so near to the sun that the attraction of the newcomer caused a huge heat-whirlpool in our sun, with the result that portions of its envelope were extruded into space by radiation pressure. Owing to the balance between gravitational attraction and centrifugal force, these new-made bodies began to circle round the sun ; by degrees the torn-off fragments of nebula condensed into spheres, radiated heat, and became satellites of the sun.

B.—How far does this theory support the assumption that life found its way to the earth from outer space ?

A.—Softly, softly ! Before I can answer that, I must give a fuller account of the relevant hypotheses. H. E. Richter was the first to

COSMOZOIC THEORIES

advance the notion that life came to this planet as cosmic dust or in meteorites thrown off from stars and planets. Subsequently Sir William Thomson (later Lord Kelvin), Justus von Liebig, and A. von Helmholtz toyed with the idea. The first impetus to the theory of a cosmic origin of life was given by the fact that in meteorites traces of carbon can sometimes be found in the form of graphite.

" CHONDREN "

Hahn even believed that in these intruders from outer space he had discovered vestiges of coralline structures to which he gave the name of " Chondren ".

B.—It seems perfectly conceivable that stellar fragments in the form of meteors should bear the germs of life to our earth, and that these germs should, in favourable conditions, undergo further development.

A.—Conceivable, yes ; but there are such formidable objections to the hypothesis, that the " cosmozoic theory " (as Preyer called it) must now be regarded as definitively discredited.

B.—But you told me that carbon was often found in meteorites, and that Hahn had detected vestiges of coralline forms. Is not that proof of the existence of life in other worlds than ours ?

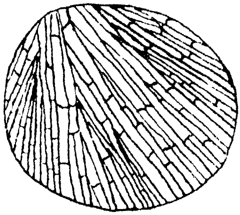

FIG. 1.- AN AUGITE CHONDRE, SHOWING RADIAL MARKINGS.

VENUS AND MARS

A.—No one can flatly deny the possibility that other worlds than ours may be inhabited. Still, the number of such worlds in which physical conditions prevail sufficiently resembling those of our planet to render the formation of organic compounds possible on them is extremely restricted. As regards the planets of our own solar system, only Venus and Mars come within this category. The fixed stars, which are white-hot suns like our own, can be ruled out because of the high temperature that prevails on their surface. Moreover, careful investigation has shown that Hahn's " Chondren ", far from being vestiges of living creatures, are only drops of molten mineral matter which have a fortuitous resemblance to the ridged or radial structure of corals.

B.—However, what is graphite but transmuted coal, which is itself a vestige of ancient forests?

A.—Agreed, in the main. Nevertheless, graphite also separates out when carbide of iron is kept for a long time at a red heat. Consequently the presence of graphite in meteors cannot be regarded as evidence of the cosmic origin of life. As you must know, a meteor is commonly called a " shooting star " because the friction it encounters as it passes through our atmosphere at an enormous velocity makes it white-hot. Notwithstanding the high resisting powers of many germs, we can hardly suppose they could survive such a temperature. Helmholtz countered this objection by saying that the germs of life adhering to the outer surface of a meteorite would be blown off immediately it entered the upper levels of the atmosphere, before the invader was heated by aerial friction. Then they could, uninjured, sink slowly to the surface of the earth. Still, inasmuch as no organic matter of any kind has indubitably been detected in meteorites, the cosmozoic theory is no more than an unsubstantiated speculation.

B.—But what has all this to do with radiation pressure, which you yourself said provided some support for the theory of the cosmic origin of life?

Svante Arrhenius

A.—Radiation pressure is one of the props of a cosmozoic theory propounded by Svante Arrhenius, a theory which diverges considerably from the one previously mentioned. Arrhenius' view is that space is full of the germs of life, which are universally diffused, constantly emitted from all habitable worlds in the form of spores, driven through the ether by radiation pressure. He supposes them to traverse space for years or ages, the majority being ultimately destroyed by the heat of some blazing star. A few however find a resting-place on bodies which have reached the habitable stage, and there undergo further development. Thus in Arrhenius' view, there occurs a process of insemination from outer space. Since at a surface temperature of 6000° Centigrade, we find, when we employ the black-shield method of estimating the pressure of radiation, that this must exceed the gravitational attraction of the sun fourfold when the diameter of the bodies under consideration is round about 1/6000th of a millimetre, it would actually be possible that such tiny objects would be driven through space by radiation pressure. Since, moreover, experiments have proved that bacterial spores in a vacuum can remain alive for long periods at a temperature of $-250°$ C., which is only 23° C. above the absolute zero, we can see it is theoretically possible that such germs projected from Mars or Venus might reach our world uninjured and fructify there. Until recently, it was generally believed

Insemination from Outer Space

Black-Shield Estimate of Radiation Pressure

Tenacity of Life shown by Bacterial Spores

Canals of Mars

that the planet Mars must be inhabited. Astronomers fancied they could detect on the surface of this planet a system of canalisation which could only be the work of intelligent beings. Of late, however, it has been generally considered that these alleged canals are no more than optical illusions. Apart from this, it has become doubtful whether the atmospheric conditions prevailing in Mars are such as to permit the maintenance of organic life.

Pettit and Nicholson

By the use of extremely sensitive radiometers, Pettit and Nicholson have been able to make precise observations concerning the temperature of Mars.

Temperature of Mars

The surface temperature at the poles would appear to be – 68° C., and that at the equator no higher than – 7° C. Also the atmosphere is extremely rarefied, and contains very little aqueous vapour, so that it must resemble that of the loftiest mountain-tops on earth. Certainly these are very unfavourable conditions for the maintenance of organic life of a kind known on earth.

Atmosphere of Venus

As for Venus, the surface of this planet is perpetually veiled by thick clouds, so that we know nothing of the conditions that prevail there.

Spontaneous Generation or Creation ?

It certainly seems most improbable that an organic germ issuing from a planet in some other solar system could survive the vast transit through icy cold and waterless space. Nor are we even certain whether, in other parts of the universe than that adjacent to our own sun, there exist solar systems in which conditions obtain similar to those of the solar system with which we are closely familiar. At any rate we have no experience of the insemination of our world from outer space, and Arrhenius' hypothesis therefore remains an idle speculation.

B.—Even if life should have come to this world from outer space, that would not solve the problem of the origin of life, but would merely transfer it to some other world.

A.—You have taken the words out of my mouth ! The question of the origin or source of life is unanswerable in the present state of our knowledge. It is an article of faith that " in the beginning " a divine creator, whose " spirit moved upon the face of the waters ", brought life into being by his fiat. It is also an article of faith if we scientists assume that the most lowly organisms originated out of lifeless inorganic matter by spontaneous generation. But even if science should some day be able to furnish direct proof of spontaneous generation, this need not shake our human faith in a supramundane creator, any more than the positive demonstration of the descent of man from the lower animals need offend the religious sentiment. But it grows late, and bedtime has come. If you like, we will continue our talk to-morrow.

SECOND EVENING

EXTRACTS FROM THE DIARY OF OUR PLANET

AGE OF THE EARTH

B.—After yesterday's talk, I couldn't get to sleep for a long time. I never imagined that there were so many unsolved enigmas, leading at every turn to fresh hypotheses and conjectures. Have geologists and palæontologists an approximate idea of the age of the earth, and when living creatures first appeared on our planet?

A.—Until recently, views concerning the age of the earth and of the various fossils in the principal strata were conflicting. The study of radioactivity, however, has provided us with means for answering these questions with a fair amount of accuracy. It must be admitted that an element of uncertainty is introduced into all our reckonings, because we cannot be certain whether the changes upon which our estimates of the age of the earth are based proceeded at the present tempo in earlier epochs, when physical and chemical conditions were so different from those which now obtain. Precise determination of the age of a rock or a geological deposit is therefore still impossible, but different methods produce results which accord so closely that we may have a good deal of confidence in our estimates. After all, where we have to do with periods of vast duration, a margin of error amounting to a few hundred thousand years matters little.

B.—I am puzzled how such calculations can be made. The history of the human race is a comparatively short one, and the earliest activities of mankind are veiled in mystery. It follows that such changes in the configuration of the earth as we have learned about from what our fathers have told us, can hardly serve as a measure.

A.—True enough. Still there are various ways of forming fairly accurate judgments as to the age of the earth. But to discuss them would take us too far beyond the limits of our chosen topic—which is biology.

B.—All the same, I am groping in the dark, and should like you to give me a few pointers here.

A.—It is difficult to deal with the matter briefly, and I must content myself with outline indications. I have already told you that long, long ago, the earth was in a white-hot molten condition.

GEOTHERMIC LEVELS IN THE EARTH'S CRUST

As cooling occurred, a crust appeared on the surface of the globe, and in due time became transformed into the firm superficies we now live upon. The next step was when the atmosphere became cool enough to allow of the condensation of aqueous vapour, which fell as rain and collected in the hollows as seas and oceans. If we bore a shaft into the crust of the earth we find that the temperature rises steadily as we descend. Of course the extent to which the temperature increases depends, in some measure, upon the conductivity and arrangement of the various strata through which we pass.

B.—No doubt the subterranean temperature will also be influenced by the daily and the seasonal variations at the surface?

A.—So little that this matter can be left out of the reckoning. The diurnal variations of temperature do not make themselves felt beyond a depth of six feet, and the seasonal variations have no influence below about eighty feet. At greater depths than this the average increase of temperature as we descend into the interior of the earth is 1° C. per 100 feet. The increase in depth which corresponds to an increase in temperature of 1° C. is known as a "geothermic level". The thickness of a geothermic level varies considerably with the nature of the rock. For instance, where volcanic masses crop out, the temperature in a boring increases much more rapidly as we descend. In a boring near Neuffen in the Swabian Alps, Branca found the geothermic level to be as little as 36·5 feet, whereas in the South African goldmines the increase as we descend is only 1° C. per 400 feet. Averaging the results obtained by borings in various parts of the world, the inference has been drawn that the thickness of the crust can only be about sixty miles, and that below this the rocks must be molten. Now let us take a glimpse into the past. If you picture to yourself the earth as a molten ball, you will realise that this ball must have continually radiated heat into outer space until its surface cooled down to the temperature at which we live to-day. Allowing for the knowledge we have about geothermic levels and about the conductivity of the various rocks,

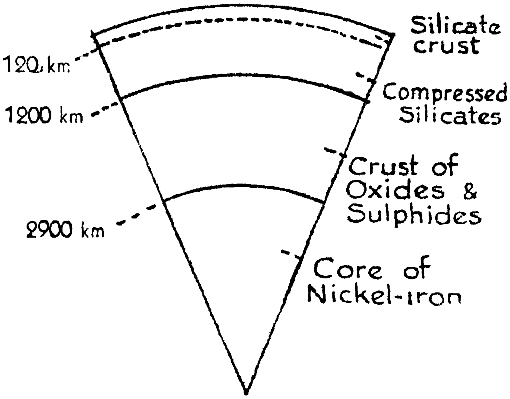

FIG. 2.—DIAGRAMMATIC SECTION THROUGH THE EARTH.

(After V. M. GOLDSCHMIDT.)

LORD KELVIN'S CALCULATIONS

Lord Kelvin came to the conclusion that the cooling process from the molten globe to the present condition of the crust must have taken from twenty to forty million years.

B.—These figures are so vast that they convey very little meaning to me.

A.—Nevertheless the period in Kelvin's estimate is far too short, for his calculations were invalidated by the fact that in his day radioactivity had not been discovered. Physicists had no idea that warmth

SOURCES OF HEAT

was continually being supplied to the earth by the disintegration of radioactive substances. Kelvin believed that, apart from being warmed by the sun's rays, the earth was steadily cooling down, there being no fresh sources of heat. It is true that the geologists and palæontologists of his day insisted that there must be a miscalculation, for the time alleged was far too short to allow for the changes that had taken place in the surface of the earth since consolidation began and for the evolution of highly organised living creatures. Adopting another basis of calculation, geologists obtained a far longer period.

B.—Please explain.

SALT CONTENT OF THE SEA

A.—When aqueous vapour began to condense out of the cooling atmosphere and to fall as rain, forming the seas, these were at first free from salt. Only by slow degrees did the ocean become salt, thanks to the mineral substances dissolved out of the earth by surface waters and springs, and carried down to the sea by the rivers. If we divide the total salt content of the ocean by the amount poured into it annually by the rivers, we obtain as quotient the number of years that must have elapsed since the seas began to form. This gives us a period of three hundred and sixty million years since the surface of the earth and the atmosphere had cooled to a temperature below 100° C., the boiling-point of water. But, according to present views, the method of calculation based upon the salt content of the sea gives results that are still too low.

B.—What are the objections to the method? Why is it unreliable?

QUICKENING OF SOLUTION

A.—The calculation assumes that in the early days when the crust of the earth began to consolidate, the solution of its mineral contents went on at the present rate. Probably this was not so. At a comparatively recent date in geological history, there occurred extensive changes on the earth's surface, with tremendous volcanic eruptions, and the foldings which gave rise to the still extant mountain chains (which are much higher than the mountain chains of earlier epochs). The consequence has been that the fall of the rivers with the associated solution and detrition are far more extensive than when the earth was younger. Quite recently man, by digging up the soil and by deforestation, has done much to intensify the same processes. The general upshot has been that far more saline material is carried seaward by the rivers than of old. If we are to rely upon the salt content of the ocean as a measure of the age of the earth's crust since rains began, we must probably multiply the aforesaid three hundred and sixty million years by three or by four.

B.—It makes my brain reel to listen to such figures.

A.—Since the study of radioactivity leads to a similar estimate, it may be accepted with a considerable degree of confidence.

B.—Please explain to me about radioactivity, and how its study gives a clue to the age of the earth.

Structure of Atoms

A.—A few decades ago it was regarded as an unquestionable truth that all bodies consist of atoms, the ultimate and indivisible constituents of matter. But, as we know to-day, the atoms themselves consist of much smaller entities, negatively charged electrons which revolve in circular or elliptical orbits around the positively charged atomic nucleus, as planets circle round the sun. Thus the atom has lost its sacrosanct indivisibility. In fact, no less than theoretically, atoms can be broken up, and in this way one element can be transformed into another. Indeed, such transformations are continually going on in nature.

The Dream of the Alchemists

B.—It follows, then, that the alchemists' dream of transmuting "base" metals into gold was not so foolish as modern scientists were of late inclined to suppose?

Radioactive Processes

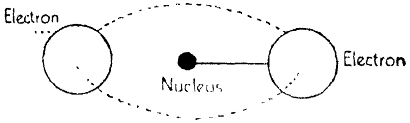

FIG. 3.—NEUTRAL HELIUM ATOM.

A.—In theory such a transmutation is nowadays once more regarded as possible. But we must avoid straying from our subject. You know that all chemical processes can be accelerated or slowed by changes in pressure, temperature, etc. There is, however, apart from this, a peculiar kind of chemical transformation which is always going on at its own tempo and in accordance with its own laws, whose working is unaffected by chemical or physical changes in the environment. This peculiar phenomenon, which is a transformation of the atom, became known to us by the discovery of radioactivity. Radioactive processes are not influenced in the slightest degree either by heating the radioactive substance to a white-heat or by cooling it down to the temperature of liquid hydrogen. At either temperature, they pursue their course imperturbably. The starting-points of these transformations are the widely diffused elements uranium and thorium, out of which, with the emission of considerable heat and the emanation of peculiar corpuscular radiations, new elements are formed in accordance with strict laws. The goal of the process, at which quiescence is achieved, is the formation of uranium-lead and thorium-lead respectively. If we start with uranium, the cycle of changes passes through uranium-X, radium, and radium emanation, to reach uranium-lead, which differs from ordinary lead in having an atomic

Uranium and Thorium

weight of 207·25 instead of 206. While the transformation is in progress, excessively minute material particles of three kinds, distinguished as alpha, beta, and gamma rays, are violently extruded. Especially interesting in the present connexion are the alpha rays, for these particles, expelled by the uranium at enormous velocity,

HELIUM

are helium nuclei which, while passing through the matter undergoing disintegration, annex two electrons, and remain as helium in the radioactive mineral. Helium has an atomic weight of 4, and is therefore, next to hydrogen, the lightest gas known. Being non-inflammable, it is sometimes used instead of hydrogen or of coal-gas to inflate airships. Before its discovery on earth it had been recognised by spectrum analysis in the chromosphere of the sun.

CALCULATION OF THE EARTH'S AGE BASED ON ATOMIC DISINTEGRATION

Since these processes of radioactive disintegration are uninfluenced by the chemical and physical state of the matter concerned, since they proceed at an invariable speed in accordance with fixed laws, and since the laws are known to us, the process in question furnishes a trustworthy means for ascertaining the age of a uranium-containing ore, and therefore the age of the rocky stratum from which the ore has been derived. A gramme of uranium ejects a hundred thousand alpha rays or helium nuclei per second. When the amount of uranium in a specimen of ore has been determined, we know how many helium atoms this quantity of uranium discharges in a second. Since one gramme of uranium discharges 100,000 atoms of helium per second, the number discharged in a year will be $3{\cdot}1 \times 12^{12}$. These atoms are so minute that, numerous though they are, at normal atmospheric pressure they will occupy a space of no more than $0{\cdot}11 \times 10^{-6}$ c.c. Consequently it will take nine million years for a gramme of uranium to liberate a cubic centimetre of helium gas. If a specimen of uranium ore contains ten cubic centimetres of helium gas per gramme, we know that the process of liberating helium must have been going on for ninety million years; and if the richness in helium be fifty cubic centimetres per gramme of uranium, the ore under examination must have crystallised out at least four hundred and fifty million years ago. We get similar results when we take as the basis of calculation the transformation of uranium into uranium-lead, which is completed in 4,500,000,000 years. In this way we can determine with considerable accuracy the age of the various geological formations.

B.—What figures have been obtained in this way?

TRILOBITES OF THE CAMBRIAN EPOCH

A.—For the Cambrian rocks, which lie below the Silurian in Wales and Cumberland, and are the oldest that contain fossils in good preservation (trilobites), we deduce an age ranging from six to seven hundred million years. As regards the pre-Cambrian strata, the

THE PRE-CAMBRIAN EPOCH

youngest must be at least seven hundred million years old, while the oldest must date back as much as fifteen hundred million years.

SEDIMENTARY ROCKS

Since the pre-Cambrian are the first sub-oceanic sedimentary rocks, we infer that the formation of the seas must have begun more than a thousand and a half million years ago. Presumably at this time there already existed on our planet the conditions which rendered possible the origination of life.

B.—Is it in the Cambrian strata that we find the first vestiges of living creatures ?

A.—No. What I said was that the oldest well-preserved fossils were found in these strata, primitive crustaceans known as trilobites, closely akin in their organisation to the crustaceans of the modern world. If we suppose life to have originated through spontaneous generation, we must assume at least as long a period to have elapsed from the first appearance of life on earth to the development of the highly differentiated trilobites as that which extended from the Cambrian epoch to our own day.

B.—In that case the age of our earth must be fifteen hundred million years.

PRIMARY ROCKS

A.—Another fallacious inference ! Assuming our calculations to be sound, at the beginning of the pre-Cambrian epoch the world had passed through childhood and youth, and was already grown up. The disintegration of the previously formed primary rocks began. Air and water and variations in temperature gnawed at these primary rocks, whose fragments were washed down from the uplands into the hollows, to form there the first sedimentary rocks—strata which contain the records of the vegetable and animal world of those days in the form of imprints and fossils. Living creatures themselves likewise participated in this work of destruction and reconstruction. Their shells and other fixed constituents played a considerable part in the formation of the sedimentary rocks. Unicellular plants and animals, such as diatoms, calcareous algæ, radiolaria, nummulites, and other tiny foraminifera predominated, swarming in the ancient seas, just as different species of the same genera swarm in the seas to-day. For instance, the chalk cliffs of Rügen and of the Kentish and Sussex coasts and the Isle of Wight, etc., are mainly composed of the shells of foraminifera. What vast quantities of living beings must have been born and have died to make, for instance, the chalk cliffs of Stubbenkammer in the Isle of Rügen, you will realise for yourself when I tell you that one gramme of chalk such as is used for writing on a blackboard may contain over fifty thousand shells of foraminifera. Stubbenkammer cliff is 400 feet high ! But before the above-mentioned processes of disintegration and reconstruction had begun, there had been the epochs during which the crystalline primary rocks were being formed—granite, syenite, greenstone, quartz-porphyry, gneiss, mica-schist, hornblende, granulite, and phyllite—the whole ranging in thickness from 30,000 to 100,000 feet. The formation of these primary rocks must also have demanded an immense period of time which is estimated at from one thousand to fifteen hundred million years. We may suppose, therefore, that from two and a half to three thousand million years must have elapsed since the earth's crust began to form after the detachment of our planet from the sun.

B.—But the severance of the glowing mass of nebula from the sun, and its cooling-down until the crust began to form, must also have taken an immense time.

Cooling-down of the Earth

A.—In this matter, scientists think of comparatively moderate figures. Jeffrey believes that the condensation of the gaseous nebula into a liquid may have needed no more than five thousand years, and that the formation of a crust on the surface of the molten globe may have begun in from fifteen to twenty thousand years thereafter.

B.—It seems to me incredible that a crust could have begun to form on a molten globe in so comparatively short a time.

The 1906 Eruption of Vesuvius

A.—Let me relate a personal experience which may help you to understand the possibility. In 1906, I saw a great eruption of Vesuvius. A stream of lava more than 2000 feet wide and thirty feet deep ran down through Boscotrecasa, destroying everything in its path. The temperature in the interior of such a current of molten rock ranges up to about 5000° C. Eucalyptus trees that were in the channel of the lava flamed up like straws. The flow ceased at about eight in the evening. By the next morning, only twelve hours later, a crust had already formed, thin indeed, but firm enough to enable us to cross without burning our boots.

Age of Various Strata

B.—I should never have believed that possible. Would you now be so good as to tell me something about the respective ages of the various geological strata, and about the appearance of vestiges of life within them ?

A.—I foresaw you would ask me that question, so I have sketched a table which will show you the ages of the various strata and a number of other interesting details ; for it is only the fossils preserved in the bosom of the earth which provide us with information (fragmentary, alas) concerning the structure and mode of life of the ancestors of contemporary organisms.

Gaps in the Geological Record

B.—Fragmentary information ? I thought the geological formations had been so thoroughly studied that a genealogical tree of plants and animals could be drawn. Recently in a big popular treatise I saw a zoological tree of this kind showing the descent of man from protozoa, with numerous lateral branches and scarcely any gaps.

A.—The wish was father to the thought ! The most convincing proof of the inadequacy of the older pictures of the kind is given by a comparison of the wealth of living forms preserved in the Silurian

strata with the poverty of the Cambrian. Whereas we are acquainted with 11,000 forms of life from the Silurian, we know a bare 800 from the Cambrian. Even the word "ancestors" ought to be placed between inverted commas, since for the most part we have no valid evidence as to the descent of contemporary species from the fossil types that are their reputed predecessors. Only in exceptional instances is it possible to draw a genealogical tree which seems to be beyond criticism, and which clearly exhibits the gradual transitions of form. Especially as regards transitional types between the various genera and classes, we must usually restrict ourselves to vague intimations. The expositors of any science discredit it when they fail to distinguish sharply between hypothesis and established facts. None the less, palæontological study in conjunction with numerous other trains of thought and investigation enable us to regard the doctrine of descent as a thoroughly well-grounded hypothesis when compared with the old dogmas of special creation.

Genealogical Trees

Doctrine of Descent and the Darwinian Theory

B.—Then the Darwinian theory is now generally recognised?

Constancy of Species

A.—Yes, so far as Darwin and his followers proclaimed the origin of all contemporary living organisms by descent and differentiation from one or a few simple forms—in contrast with the views of Cuvier and his school, who believed species to be inalterable. But it is otherwise as regards Darwinism in the narrower sense of the term, the theory of natural selection through the preferential survival of the fittest, of those creatures best adapted to environing conditions (this process, in conjunction with variability, being regarded as the dominant cause of the "origin of species". As to this theory, the last word has not yet been said). To-day there is more divergence of views among biologists concerning the forces that have led to the gradual transformation of organic types and their progressive development, than there was a few decades ago, when the victory of the theory of natural selection seemed assured.

B.—A fuller explanation of this would be interesting and helpful.

A.—I will deal with the question later, when we come to the general discussion of the various theories of evolution. Before that, it will be well to consider the earliest records of the history of the earth, so that you may become acquainted with the primary manifestations of life on our planet and with the other proofs of the doctrine of descent. If you study this table showing how the most important classes of animals and plants have been preserved in the rocks, you cannot fail to note that in the oldest of the fossiliferous formation, the Cambrian, there are to be found specimens of no more than a few of the classes and orders extant in the contemporary world. In

First Traces of Life

the pre-Cambrian stratum, which underlies the Cambrian, there are only obscure vestiges of the lowliest animals and plants. The rocks below the pre-Cambrian are called " azoic ", because they are devoid of any remnants of life.

B.—Then we have to assume that life originated during the pre-Cambrian epoch ?

Eozoon Canadense

A.—This would be too far-reaching an assumption. There is a good deal of reason for the belief that the deposits of graphite found in some of the crystalline schists must be of vegetable origin. About seventy years ago, in Canada, there were discovered in crystalline limestone what were believed by J. W. Dawson to be the vestiges of an ancestral foraminifer. He gave the supposed creature the somewhat pompous name of Eozoon canadense. Similar appearances were later detected in some of the European gneisses. Probably they are not organismal structures at all, but only mineral concretions, serpentine granules imbedded in limestone.

Explanation of the Gaps in the Geological Record

B.—When I recall how many hundreds of thousands of species of animals and plants there are, and how, in the course of generations, billions upon billions of each species must have lived and died, it seems to me that there ought to be abundant remnants of them all.

A.—You underestimate the difficulties in the way of an exhaustive examination of the earth's crust, and also the difficulties in the way of the preservation of fossil remains. About three-fourths of the earth's surface are covered by water, and are therefore out of reach. Our deepest borings do not extend below 10,000 feet from the surface, and are like scattered pinpricks in the rind of an orange. Thus our knowledge is mainly restricted to the places where the deeper strata are exposed in canyons or in faults. Furthermore, the larger part of the fossil-containing strata has been destroyed by weathering and denudation. Even where the fossils have escaped these casualties, many of them have been rendered unrecognisable by pressure or by volcanic processes.

B.—True, I had not allowed for these contingencies.

A.—There are additional reasons for gaps in the geological record.

Formation of the Sedimentary Rocks

Vestiges of ancient plants and animals are found only in the sedimentary rocks, formed at the bottom of seas or lakes. No, I exaggerate when I say " only ". On dry land, the winds have led to the formation of weathered rocky remnants, and some of these contain fossils.

Predominance of Submarine Deposits

Nevertheless, these and the fossiliferous fresh-water deposits are of trifling extent when compared with those that have been laid down in the sedimentary rocks formed beneath the sea. Naturally, then, we have far more abundant fossils of sometime marine animals and plants than of those creatures that used to live on dry land or in fresh water. To quote Darwin (concluding paragraph of Chapter Ten in *The Origin of Species*): " the geological record " is " a history of the world imperfectly kept, and written in a changing dialect. Of this history we possess the last volume alone, relating only to two or three countries. Of this volume, only here and there a short chapter has been preserved; and of each page only here and there a few lines ". No doubt, since Darwin's day, the arduous labours of geologists have filled in many gaps, but we must not pitch our expectations too high. Speaking generally, land-dwelling organisms are only preserved as fossils when their remains chance to have found their way into a lake or river to become quickly imbedded in mud or sand. Animals that die on dry land, speedily undergo putrefaction, and after a while their skeletons moulder away into dust.

B.—Yes, I have observed that myself. A few years ago, near where I live, buildings were erected upon an abandoned cemetery. I was astonished, watching the excavations, to find how few bones were left to show that human bodies had once been interred here for their " eternal rest ".

The Older the Rocks, the Fewer the Fossils

A.—It is not surprising, then, that palæontology is a science in which there are numerous hiatuses. Indeed, the wonder is that so many vestiges of earlier life have been preserved. To-day we know more than a hundred thousand fossil species. After my previous explanations, you will understand readily enough that the older the rocks, the fewer the fossils, until, at length, in the pre-Cambrian strata, there are no undeniable remnants of organisms at all. Obviously, too, we can only expect, in " the record of the rocks " to find evidence of animals that had an endoskeleton or an exoskeleton: fossilised bones of vertebrates; the chitinous cuirasses of beetles and crustaceans; the cretaceous shells of foraminifera; the exoskeletons of articulata; the shells of molluscs; and the like. We must regard it as a special stroke of luck when, here and there, soft parts have been preserved, or at least have left imprints in the rock, as in the case of the famous traces of medusæ in the lithographic schists of the upper Jurassic near Solnhofen and Eichstätt. More especially the most primitive forms of life, the shell-less protozoa and their presumably simpler predecessors, have been erased for ever from the diary of our planet. That is why we are unlikely to get beyond vague suppositions regarding the first appearance of organisms in the world.

Traces of Medusæ

B.—If I shall not disturb your trains of thought, I should like to ask a few questions.

A.—Ask freely. The great thing is that no obscurities should be left in your mind.

B.—When did the formation of the sedimentary rocks in which fossils are found begin?

BEGINNING OF DENUDATION

A.—I am not in a position to give you precise figures; but we are obviously entitled to assume that the denudation and solution of the primary rocks must have begun as soon as the atmosphere was cool enough for aqueous vapour to fall as rain, and the earth cool enough to allow rivers and seas to form.

B.—Are these stratified rocks distributed in equal thickness over the surface of the earth?

A.—A little reflection will show you that that is impossible. The main sedimentary deposits, consisting of the agglomerated detritus washed down from the land after disintegration of the primary rocks by the influences of air, ice, and water, are necessarily formed at the bottom of the sea. True, in the course of the earth's history, owing to the folds resulting from the gradual cooling-down of the earth and owing to eruptive activities, there have been continual changes in the distribution of lands and seas. Where in one epoch the ocean rolled, in another a continent has appeared, with the result that there is no spot in the world showing an unimpaired succession of geological strata, but everywhere there are lacunæ. Borings show in many places that submarine sedimentary rocks are overlaid by fresh-water sediments, on the top of which lie submarine sedimentary rocks once more, surmounted by what is now dry land—all these changes affording evidence that the area in question has repeatedly become land after lying for long ages beneath the sea. But even in regions where the changes have been less extensive, and where recent submarine sedimentary rocks are directly superposed upon more ancient ones, the constitution of the strata and the character of the fossils they contain undergo a progressive change.

DISPLACEMENTS OF LAND AND WATER

B.—What inferences are we to draw?

A.—That here, likewise, the depths of the sea and the associated physical and mental conditions have been subject to persistent change, and that the living creatures whose fossils have been preserved either became extinct through inability to adapt themselves to the new state of affairs, or else were compelled to migrate into a more suitable environment.

B.—Surely these displacements of land and sea came to an end long since? There is no reason to suppose that Germany, for instance, will some day lie once more at the bottom of the sea?

A.—You are mistaken. Even since human historical records began, areas of land have passed beneath the sea and then re-emerged. You yourself have stood upon ground which has suffered these contingencies.

THE SERAPEUM AT POZZUOLI

B.—I?

A.—Don't you remember the temple of Serapis on the northern shore of the Bay of Naples?

B.—Very well, but what on earth has the Serapeum to do with the matter in hand?

A.—Three pillars of the ancient temple were still standing. Do you recall anything peculiar about them?

B.—Yes, there was a circle of deep holes in each of them, at a height of ten or twelve feet from the ground.

A.—Do you know how those holes were made?

B.—I suppose they were due to weathering.

A.—You are not a keen observer. Why should such a weathering-process begin at a particular height from the ground, and extend upwards for a few feet, although the surface of the pillars was in excellent condition above and below this zone?

B.—I gave no thought to the problem.

A.—Well, think about it now.

B.—Nothing occurs to me by way of explanation.

Stone-Boring Mussels

A.—Yet the solution of the enigma is obvious. The holes were made by the stone-boring mussel, or date-shell, Lithodomus lithophagus, which abounds in the Mediterranean. When the land sank, the lower part of the columns was covered up to a height of ten feet by volcanic scoriæ and was thus protected from the stone-eaters. The date-shells could only get to work upon the part of each column that was freely exposed to the sea-water. In 1538, at the time of an eruption of Monte Nuovo (now seemingly extinct), the site of the temple rose once more above sea-level, and the stone-boring molluscs died. But the work they did during the period of submergence remains to tell us the story.

Monte Nuovo

B.—I should never have hit upon this explanation unaided. How one wanders through the world with one's eyes bandaged. Travel becomes far more stimulating when one learns to read the palimpsests which everywhere confront one.

Scandinavia is rising out of the Sea

A.—Such speedy, such " instantaneous ", elevations and depressions of small areas of land are generally the result of earthquakes or the accompaniment of volcanic eruptions in the neighbourhood. There are also in progress, during our own times, slow " secular " changes in level, amounting sometimes to no more than a few feet in a century. For instance, the Scandinavian peninsula has been steadily rising for a long time, so that we find along the coast old " sea-beaches " which are now as much as 500 feet above the present high-water mark.

B.—You must forgive me if my curiosity is still unsatisfied. Even though the full series of geological strata does not exist everywhere, because certain sedimentary strata were not formed in certain regions which were persistently above sea-level—so that we find carboniferous instead of Devonian rocks directly superposed upon Silurian—still, I suppose the deepest stratum is invariably the oldest.

A.—Theoretically one might think that ought to be the case, but in fact we only find the condition you describe in areas where the original arrangement of the strata has not been disturbed by foldings of the crust sufficient to reverse the normal stratification, or by volcanic processes giving rise to what are called " intrusive " layers. Often by folding or plication the strata are pushed into a vertical position or may even be turned upside-down, so that the older strata lie above the more recent formations. Occasionally you will actually find sedimentary strata overlaid by primary rocks.

B.—Then I don't understand, if such mix-ups are frequent, how the respective ages of the various strata can be determined.

A.—In part the fossils give us a clue ; and, conversely, the kind of rock gives an indication as to the age of the fossils it contains.

B.—Surely that is arguing in a circle ?

A.—Not really. Let us suppose that we are in a region where,

DISLOCATIONS

since the deposit of the sedimentary rocks in normal fashion, no dislocation or transposition of strata has occurred. In this region, we ascertain the normal succession of the strata and what fossils are appropriate to each. Thus we learn that particular organisms are

STANDARD FOSSILS

characteristic of this formation and of that. The fossils of a certain type then serve us as standards when we have to deal with an area in which extensive dislocations have occurred. Of course the most useful of these standard types are organisms, whether animal or vegetable, which were able to adapt themselves quickly to a changing environment and which had a wide geographical distribution. Let me refer once more to the trilobites, primitive crustaceans found in the Cambrian, the Silurian and also in the more recent of the palæozoic formations. As compared with their Cambrian ancestors, the later trilobites acquired a new faculty, becoming able to roll themselves up like hedgehogs. If, therefore, in any rock we find a rolled-up trilobite, we can be certain that the rock in question is post-Cambrian. The structure of the fossilised organisms found in any stratum enables us, moreover, to draw valuable conclusions as to the climate, the salt-content of the sea-water, and its temperature, in the days when the stratum was being laid down. I need hardly tell you that any such " normal " succession of strata does not warrant our drawing more than fragmentary inferences as to the history of the earth ; but by juxtaposing a number of fragments derived from all parts of the world we become enabled, at last, to form a fairly clear and trustworthy picture of the transformations in the surface of our globe and in its inhabitants.

B.—You have cleared up my difficulties. Now I am eager to hear some details about the lives of the most primitive animals.

A.—It is very late, and I think we had better wait till to-morrow evening for that.

THIRD EVENING

FOSSILS

RISE, BLOSSOMING, AND DECLINE

A.—In accordance with your wishes, we will to-day embark upon a cursory trip through the ages. But before we start, let us take another fugitive glance at our table. In elucidation, I should like to point out that the thickness of the lines is an indication of the abundance of the species and types belonging to the various classes of the animal and vegetable kingdoms as they manifest themselves in the different formations. You see, for instance, that the brachiopods flourished most copiously in the Devonian and Carboniferous epochs, had a second outburst in the Cretaceous, and have since then remained on much the same level of abundance.

B.—You are using too many technical terms. What are brachiopods?

A.—They are molluscs which outwardly resemble mussels, but have, instead of right and left shell-valves, an abdominal and a dorsal shell. They are fixed to the sea-bottom, not migratory. In structure and development they show a kinship to certain worms. But if you are interested in such details, you had better look them up in a textbook of zoology. What is relevant to our present purpose is that you should note in the table how many classes of animals (for example the graptolites, which are akin to the modern hydrozoa) have a brief worldwide diffusion, and then become extinct. We see the same thing in the case of the trilobites, whose blossoming season was in the Silurian and the Devonian, while they died out towards the end of the Permian. The lowest class of vertebrates, the fishes, make their appearance in the Silurian with a few primitive types. They quickly increase in number, and, with many fluctuations, have continued on the whole to do so down to our own day. The first amphibia and reptiles are found in the Carboniferous. They were most luxuriant in the Lias, the Jurassic, and the Cretaceous; and the reptiles of the modern world are but dwarfs and belated survivals when compared with the titans that then existed. In the Lias we find the remains of the first warm-blooded animals, namely

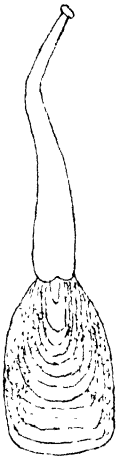
FIG. 4.—LINGULA, A BRACHIOPOD WHICH HAS PERSISTED ALMOST WITHOUT CHANGE FROM THE CAMBRIAN EPOCH TO THE PRESENT DAY.

birds and marsupials, the types of both becoming more and more numerous and more and more widely diffused in subsequent epochs, to effect the conquest of land, water, and air. Not until the Tertiary

First Traces of Man

do we find the first but still disputable evidence of the appearance of man on the stage. As you can see for yourself, this rough survey suffices to show the evolution of the organic world from few and simple to many and complex forms. This applies to the vegetable kingdom as well as to the animal. There are no signs of the higher flowering plants having existed before the Cretaceous. Within each class, moreover, whether animal or vegetable, we note the same gradual transition from simple to highly organised types.

B.—I agree. The table shows this very clearly.

A Journey through the Ages

A.—Now let us set out on our journey. We will begin once more

Trilobites of the Cambrian

with the trilobites of the Cambrian. These extinct crustaceans (of late, systematologists have relegated them to the arachnids, but that is not a point which need concern us now) were cosmopolitan, the same or closely allied types being found in the Cambrian of North America, England, Bohemia, etc. Since they must have been cumbrous creatures, crawling slowly on the bottom of the sea, we cannot ascribe their wide diffusion to their own powers of locomotion, but must presume that they were distributed in the larval state by oceanic currents. The leading characteristic of the trilobite is the division of the body into three parts, an axial portion (the tergum) and two lateral portions (the pleura). Here is a sketch of one of the most important and typical Cambrian species, Dalmanites socialis. The anterior end of the body, or head, consists of a shield furnished with long horns; the body is formed of a number of coalesced segments, then comes the tail or pygidium, poorly developed in dalmanites, but of considerable size in many other trilobites. As in crabs and lobsters, the back was protected by a strong and rigid carapace, whereas the ventral surface, to which the legs and other appendages were attached and where the gills were situated, must have been comparatively soft. As far a we know, the Cambrian trilobites were blind, whereas in the Sil

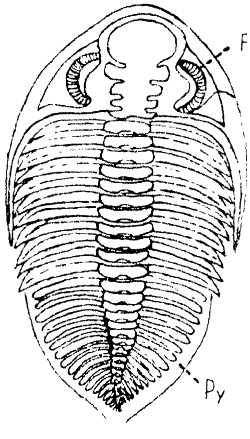

Fig. 5.—Dalmanites socialis, a Trilobite from the Silurian, whose fossilised remains form extensive Strata.

F, compound eye; Py, pygidium.

strata we find trilobites equipped with well-developed facetted eyes. What inference do you draw from these observations ?

B.—That the Cambrian trilobites lived in the depths of the sea, at levels to which no light could penetrate.

CONDITIONS OF LIFE IN THE CAMBRIAN

A.—Excellent, but there is another possibility. Perhaps in those early days the terrestrial atmosphere was, like that of Venus now, so heavily laden with clouds that the sun's rays could not pierce them, and eternal twilight prevailed.

B.—Are any other animals besides trilobites known to have existed in the Cambrian age ?

A.—Certainly. I have already mentioned the brachiopods. Besides these, there were lowly mussels and other " shellfish ", snails, and early echinoderms (sea-urchins, etc.), the so-called cystoidea. Animals of higher type are completely lacking. Even the brachiopods are only represented by small and primitive forms. Not until we reach the Devonian strata do we find them developing into an important class containing numerous species. Then a decline sets in, and to-day the brachiopods are represented by no more than a few degenerate forms leading inconspicuous lives in the depths of the sea.

B.—What about the vegetable kingdom in those early times ?

A.—The Cambrian flora is as exiguous and primitive as the fauna. As far as we actually know, the only plants then extant were simple marine algæ. Presumably there were also many unicellular organisms, but no record of them has been preserved in the rocks. Much greater

SILURIAN

variety of forms is found in the Silurian epoch. Here, likewise, trilobites are the most conspicuous animals ; but, as already said, the Silurian trilobites have well-developed facetted eyes, in contradistinction to the trilobites of the Cambrian. Trilobites in general afford a classical example of progressive development and of adaptation to changing conditions.

B.—You said a little while ago that the Silurian trilobites, in contrast with the Cambrian but like the extant woodlouse (another crustacean), could roll themselves up. Was the faculty acquired as an adaptation to changed conditions ?

A.—The new power is perfectly explicable in this way. In the Cambrian the trilobites were probably the only animals of considerable size (some were as much as two feet long). Since they had no enemies to fear, they needed no special protective devices. But a change came over the scene in Silurian and later times. The

CEPHALOPODS

Silurian seas already swarmed with cephalopods, nearly allied to the cuttlefish of to-day, and having like predatory habits. The peaceful days of the trilobites were over, for the cephalopods ranged up to six feet in length, and doubtless found the comparatively soft bellies of the primitive crustaceans easy points of attack. The acquisition by the trilobites of the power of rolling themselves up in such a way that the soft parts were protected by the dorsal cuirass must have supplied a valuable means of defence.

B.—What other kinds of animals existed in those early days ?

Progressive Evolution

A.—Slowly, slowly ! I want to go on talking to you about the cephalopods, for they offer so excellent an example of progressive evolution. Many of these molluscs have shells, and it is these which have been preserved in the geological record. In the oldest strata, we find only species with long, straight shells, divided into chambers. In more recent strata, we gradually begin to find shells rolled up in one plane from behind forward. This tendency to the rolling-up of the shells increases in the Middle Age of the earth, but there is not at first any adhesion between the coils, however closely they are approximated. By degrees, as we approach more recent times, we begin to find forms resembling the contemporary nautilus, in which the whole shell is completely surrounded by and firmly attached to the outermost chamber, which is the organism's real dwelling-house.

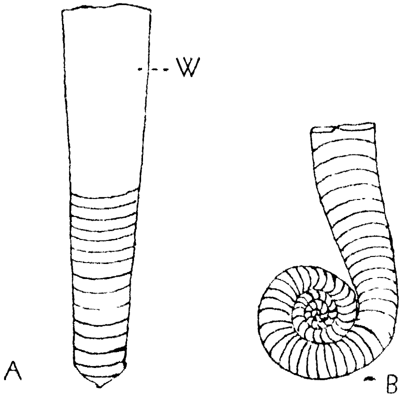

Fig. 6.—Fragments of the Shells of Silurian Cephalopods.

A, Orthoceras timidum, with straight shell ; B, Lituites lituus, in which the end of the shell is convoluted ; W, living-space (missing from B).

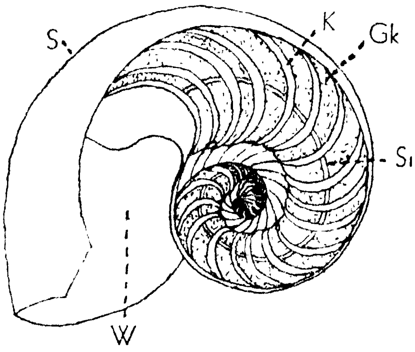

Fig. 7.—Shell of an extant Nautilus (Nautilus pompilius) in Section.

S, shell ; W, living-space ; K, partition ; Gk, air-chamber ; Si, siphon.

Increase in Size

I may refer in this connexion to another phenomenon, which is almost universal. An increase in the creatures' size proceeds hand in hand with growing complexity of organisation. The largest types are mostly found in the geological formations in which the cephalopods attained their fullest blossoming. I will tell you more about this matter subsequently, in another connexion.

Now I will answer your question. In the Silurian, we already find fossils of higher crustacea, the eurypteridæ, some of which are as much as six feet long. The Cambrian contains smaller predecessors of these. Whilst the early Silurian trilobites were exclusively marine, these animals subsequently found their way into brackish water, and later even, into fresh water. In the Silurian we also

THE FIRST VERTEBRATES

find the first vertebrates, lowly organised fish akin to the contemporary sharks. But it is not until we reach the Devonian that we find the fishes beginning to play an important part. Most characteristic of this epoch are the placodermata or " armoured fishes ", in which the front half of the body is protected by strong bony plates.

PULMONATE FISHES

In the Devonian, we already find forerunners of the dipnoi or lung-fishes, which are supposed to be transitional between fishes and amphibia. In widely separated regions of the world there are still to be found various members of these remarkable creatures, which appear to be survivals of a once important order now undergoing extinction. In the Australian rivers, for instance, there is the barramunda, Ceratodus forsteri. In Africa, there is the mudfish, Protopterus annectens, which, besides six gill-arches, has three external gill-tufts, such as are typical of many amphibia. The home of a third species, the South American mudfish, Lepidosiren paradoxa, is the Amazon. In youth lepidosiren likewise has external gill-tufts in addition to internal gills. The resemblance of these mudfishes to amphibia is intensified by the occurrence of periods of pulmonary breathing. When, in the dry season, the waters in which they live evaporate, the gills pass out of function, and the work of aeration of the blood is taken over by the swimming-bladder, which plays the part of a primitive lung. An important confirmation of the hypothesis that the amphibia are the descendants of forms similar to the surviving dipnoi (fish that have " two kinds of breathing ") is that the lung-fishes appear in the geological record before the amphibia. It seems dubious, however, whether the fossil ancestors of contemporary mudfish were, in fact, occasional lung-breathers, for most of them lived in broad bays of the sea which can hardly have been liable to temporary dryings-up.

B.—Is it not true that the lung-fishes can survive spells of dry weather lasting many months?

CARBONIFEROUS STRATA

A.—Yes, and to that matter we shall return. Meanwhile, let us continue our journey, though I shall have to restrict myself to the mention of a few characteristic representatives of the early animal world. In the Carboniferous, we find vestiges of a far more abundant and highly developed life—especially of plant life. This stratum receives its stamp above all from huge tree-ferns, gigantic horsetails (equisetum), and palms of one sort and another. The marshy forests sheltered enormous numbers of insects, spiders, scorpions, and millipedes. It was in such swamps that the first amphibia appeared, precursors of the labyrinthodonta or stegocephala, an order which appeared and flourished in the Permian and the Trias and then speedily died out. As examples I may mention the ungainly anthracosaurus, an animal whose shape resembled that of a salamander ; and the mastodonsaurus, whose skull was more than a yard long. Reptiles probably branched off from this stem. The blossoming-time of the amphibia came, however, after the Carboniferous,

SAURIANS

in the Permian. In the Permian, too, we find the first true reptiles, creatures which attained their highest development and spread all over the world in the Trias and the Jurassic. The reptiles of the Permian were comparatively insignificant creatures, belonging to the two orders of the rhynchocephalia and theromorpha. Of the rhynchocephalia, which many biologists regard as the ancestral stem of the lizards, the crocodiles, and perhaps the tortoises, only one species

THE TUATARA

has escaped extinction, the tuatara (Hatteria punctata or Sphenodon punctatum) of New Zealand, a huge lizard, which seems likely to die out before long.

B.—Is not the tuatara the strange creature with three eyes ?

A.—Patience awhile. We shall discuss that matter when we come to speak of rudimentary organs. In the Middle Age of the earth, which comprises the Trias, the Jurassic, and the Cretaceous, reptilian life flourished most abundantly. In the seas of those days swam, among other strange forms, ichthyosauruses (somewhat resembling dolphins in appearance, though of an entirely different structure) and long-necked plesiosauruses. The ichthyosaurus ranged up to nearly forty feet in length, and its whole body was adapted to marine life. Its limbs, containing many bones and joints, were modified into oars ; its long and powerful tail ended in a bilobate vertical fin ; and on its back it had another fin, thick, muscular, posteriorly directed, and pointed. Alike ichthyosauruses and plesiosauruses were voracious beasts of prey, feeding chiefly on fishes and molluscs.

B.—It amazes me that so much can have been learned about the habits of these extinct monsters.

VIVIPAROUS ANIMALS

A.—We know more than that. The fossils of females in an interesting condition show that ichthyosauruses did not lay eggs (as do most reptiles) but gave birth to live young.

OVIPAROUS MAMMALS

B.—I thought that only mammals did that.

A.—You were mistaken. Among the various phyla of the animal kingdom we find a great many viviparous species : for instance, the marsh snail, Paludina vivipara ; and among the lizards, the mountain lizard, Lacerta vivipara. On the other hand, the lowest mammals, the monotremata, to which order the ant-eater (echidna) and the duck-billed platypus (Ornithorhyncus paradoxus) belong, lay soft-shelled eggs about three-fifths of an inch in length. Only the first segmentations of the fertilised ova take place within the uterus. Then the eggs are laid and incubated.

GIGANTIC TYPES OF ANIMAL

Turning to the fossils of sea-coasts and river-beds, we encounter there huge crocodilian reptiles such as teleosaurus and belodon. The land was also peopled by dinosaurs, some of enormous size, among the best-known of which are atlantosaurus (more than sixty feet long) and brontosaurus (almost as large). The skeleton of a kindred beast, gigantosaurus, discovered in what used to be German East Africa, is nearly a hundred feet long. Still, these titans were comparatively harmless, slothful creatures, being vegetarians. Their intellectual faculties, too, were at a very low level.

B.—How can that have been ascertained ?

A.—Their diet is shown by the character of their teeth, and their stupidity by the fact that their skulls (and consequently their brains) were exceedingly small in relation to their bodies.

THESE PRIMITIVE TITANS NO LARGER THAN THE CONTEMPORARY ONES

B.—How can it be explained why, in the world's early days, animals attained such enormous dimensions when compared with those which now exist ?

A.—No one can explain something which is not a fact. There is no ground for the common belief that the huge animals of the ancient world were larger than any which exist to-day. The largest species of whales, cachalots and others, may have a girth of close on forty feet, a length of nearly a hundred, and may weigh a hundred tons. These are not outclassed in size by any of the extinct saurians. Even the biggest contemporary mammals—the elephant, the giraffe, the rhinoceros, and the hippopotamus—are fair rivals to the great saurians of ancient days. Turning to extant fishes, we find that some of the sharks (the basking-shark, for instance) attaining a length of from fifty to sixty-five feet, are as large as most of the extinct saurians. There is a subjective reason for the widespread conviction that many of the fossil reptiles were larger than any creatures now alive in the world.

B.—Please explain.

A.—Does not a Shetland pony nine hands high look to you a dwarf. Even an ordinary pony seems exceedingly small. But a dog as large as a Shetland pony would appear gigantic. Why ? Because we are used to large horses and small dogs. The same applies to the animals of the primeval world. In absolute dimensions they are no larger than certain contemporary animals ; but we find huge fossil creatures belonging to a phylum of the animal kingdom which is now represented only by comparatively small specimens. We are so used to small lizards and small snakes, that a lizard a foot long or a python twelve feet long and as thick as our own arms seems to us enormous. It is not surprising then that we are impressed by the dimensions of the extinct saurians, many of which were, indeed, very large beasts. Our own time is the hey-day of the mammals, and some of them are of titanic proportions. The earth's Middle Age was the hey-day of the reptiles.

Beasts of Prey

B.—During what you call the earth's Middle Age, were there already beasts of prey ?

A.—If you mean mammals resembling lions and tigers, no. Nevertheless, many of the reptiles were dangerous carnivora which preyed upon their larger and smaller reptilian contemporaries. In the North American Cretaceous, we find fossilised specimens of Tyrannosaurus rex, which stood erect to a height of thirty-five feet. Its front limbs were almost atrophic, but it had a tremendous development of hind legs and tail. In these respects it resembled a kangaroo, and probably moved about by hopping, somewhat like that marsupial. For the sake of completeness, however, I wish to mention among the vegetarian extinct saurians the animal known as stegosaurus, to which a double row of bony plates projecting from the back must have given a menacing aspect. These animals, which ranged up to thirty feet in length, were plantigrades, with stumpy legs, and toes that had undergone modification into hoof-like structures. Even larger was the iguanodon, sung by Scheffel in his verses that begin with : "There is a rustling in the horse-tail grass. . . ."

B.—Iguanodon. That is the monster which has been reconstructed in front of the Berlin Aquarium ?

A.—Yes, you are right. The iguanodon, too, hopped like a kangaroo. Big though it was, it was a harmless vegetarian. Finally I would speak of the family of the ceratopsidæ, distinguished from the other dinosaurs by the harmonious development of the legs, which had hoofed toes, by a comparatively short tail, but a big skull which was nearly six feet long and had a horn three feet in length. In fact, the creature was something like a rhinoceros in aspect.

Conquest of the Air

B.—Were there birds yet ?

A.—No ; but the reptiles had already achieved the conquest of the air. There were flying saurians or pterosaurians. The best known are the pterodactyls, which ranged in size from that of a sparrow to that of an eagle. Their bones, like those of birds, were hollowed out into air-containing cavities, and in general their bodily structure was adapted to flight.

B.—Had they feathers ?

A.—No. Their front limbs had been modified more after the manner of a bat's wing. The outermost of the four fingers of the hand was enormously elongated and was larger than all the rest of the arm. From this finger, a wing-membrane stretched to the body and the hind limb. In the North American Cretaceous has been

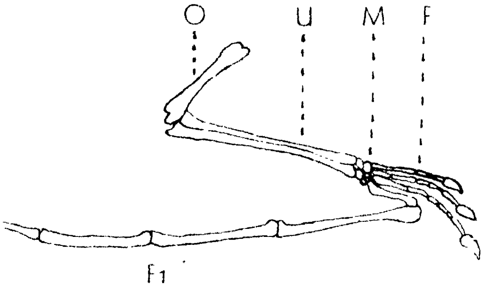

Fig. 8.—Arm of Pterodactyl, a Flying Saurian. (From the lithographic schists of Solnhofen.)

O, arm-bone ; U, the two bones of the fore-arm ; M, metacarpal bones ; F, fingers ; F1, the enormously elongated finger upon which the wing-membrane was tensed.

found a fossilised specimen of a very large flying saurian, known as pteranodon. Its wing-span was nearly twenty feet.

Exaggerated Evolution

A small digression will be helpful here. When we undertake a general survey of organic evolution, we note in various species or classes of animals a tendency to marked specialisation and towards a one-sided adaptation to peculiar conditions. This led to such exaggerated results as we see in the brachial skeleton of pteranodon. Of course this extreme adaptation to the prevailing conditions gave the species concerned notable advantages over its less specialised competitors, but it entailed serious dangers. By artificial selection man is able, in the case of " pedigree " domesticated animals, to obtain results analogous to the exaggerated natural evolution we have just been considering. Through breeding from carefully chosen specimens, particular faculties or organs can be developed to an extraordinary degree. For instance, the amount of milk furnished

The Milch-Cow " Fröhsinn "

by cows can be amazingly increased. The East Frisian milch-Cow " Fröhsinn ", which won the first prize at the Leipzig exhibition in 1928, yielded 2430 gallons of milk in a year—an average of nearly

Inferiority of " Thoroughbred " Animals

seven gallons per day. Racehorses have been artificially developed for speed, the whole muscular and bony system having been modified with this end in view. We are apt to regard such " thoroughbreds " as superior in every way to the natural types out of which they have been evolved by artificial selection. From the biological standpoint, this is not the case. While they remain under man's guardianship, these specialised creatures can fulfil their special tasks better than normal horses, cows, etc., but, in fact, their bodily harmony and their vital power have been impaired. If you were to turn an English racehorse or the milch-cow " Fröhsinn " loose upon the prairie to look after itself, it would be unable to sustain the struggle for existence as do less highly specialised congeners, and would

EVOLUTION NOT REVERSIBLE

perish. The same principle applies to animals which have been unduly specialised by nature in adaptation to environing conditions. As long as the environment remains unchanged, their specialisation gives them peculiar advantages in the struggle for existence. But as soon as the conditions vary, they are likely ere long to be weeded out, for evolution is not (or is difficultly) reversible. An organ which, in the course of millions of years, has become atrophic or has disappeared, cannot be reproduced. Still, if the species concerned is in other respects viable, a substitute for it may be provided.

LEATHERY TURTLES

B.—I think I should understand better if you were to give me a concrete example.

A.—In one order of marine turtles, there has been observable since the Jurassic a retrogression of the rigid carapace. Later turtles, however, have once more a carapace. You will say that I am contradicting myself. This is not so, however. The original cuirass of all tortoises and turtles consisted of bony plates, but the later specimens of this order of reptiles could not reproduce a cuirass of such a kind, once they had lost it. Since the creatures needed a carapace as a protection from their enemies, and since they were not so highly specialised as to be weeded out in the struggle for existence because they had lost their covering of bony plates, nature found them another way of supplying the requisite. By degrees their skins became thicker, and were transformed into a leathery coat. The irreversibility of

DOLLOSCH'S LAW

phylogenetic development (racial evolutionary history), the principle known as Dollosch's law, explains the rapid extinction of many types which had become singularly well adapted to their surroundings. They perished as soon as conditions changed.

HOUSTON STEWART CHAMBERLAIN

B.—Then you do not share the opinion of Houston Stewart Chamberlain to the effect that "thoroughbreds" are masterpieces of perfection, and may give us valuable pointers for the ennoblement of the human race?

HARMONIOUS PERFECTIONMENT

A.—No; H. S. Chamberlain's inferences were unwarrantable. What we have primarily to aim at in attempts to improve the human stock is a harmonious perfectionment of bodily and mental characteristics. But, as you will learn when we come to study the laws of heredity, this cannot be achieved by artificial selective breeding.

RACIAL HYGIENE OR EUGENICS

B.—You puzzle me. Is there not a great deal of talk nowadays about racial biology, racial hygiene, and the purposive breeding of a better human stock ?

A.—There is ample justification for a reasonable racial hygiene and for eugenics. Not until eugenic ideas have become widely known and accepted, will it be possible, with their aid, to counteract the racial decline (the dysgenic movement) which has manifestly been going on in Europe for many centuries. But the possibilities in this direction will remain obscure to you until you have become acquainted with the fundamental laws of heredity. You will have to wait a while for an answer to your question. It behoves us now to pick up the thread we recently dropped.

ARCHÆOPTERYX

One of the most interesting Jurassic fossils remains to be described. In that formation, side by side with the flying saurians, we find another conqueror of the air. The term " conqueror of the air " is perhaps a trifle stilted, for the flying powers of the celebrated archæopteryx were still somewhat rudimentary. As yet only two specimens of this strange primeval bird have been discovered, both of them in the lithographic calcareous schist near Solnhofen. Why do you suppose the finding of archæopteryx to have aroused so much interest in cultured circles ?

B.—Because archæopteryx was the earliest bird in the geological record.

A.—That alone would not account for the excitement, for archæopteryx would not therefore have seemed more important than the earliest representative of any other phylum of the animal kingdom. Look at this drawing. Does anything in the bird strike you as remarkable ?

B.—Yes, the long tail, containing many vertebræ ; such a tail as I have not remarked in the skeleton of any other bird.

A.—Indeed, the tail in question is a noteworthy feature of the fossil. But, speaking more generally, what makes archæopteryx so important as confirmatory evidence on behalf of the theory of evolution is the fact that the body of this creature, which was about as large as a pigeon, exhibits such a strange mingling of reptilian and avian characteristics. Thus it forms a link between two branches of the animal kingdom that are widely separated to-day. Archæopteryx is the fossilised proof that at least a part of the present bird world must have sprung from reptilian ancestors. Did we know only contemporary reptiles and birds, no one would have hit upon the supposition of so intimate a kinship. Archæopteryx, however, is neither genuine bird nor typical reptile, but a link between the two phyla. The plumage that covered the whole body was developed on the wings into long wing-feathers. Furthermore, the structure of the

TRANSITIONAL FORMS

bones, the closed cranium, the existence of lachrymal fossæ, the absence of temporal fossæ, the slit-like nostrils, and the formation of the shoulder-girdle and the hind limbs, combine to make archæopteryx a bird rather than a reptile. On the other hand, archæopteryx's sternum lacks the carina, which is so prominent in good flyers, serving for the attachment of the powerful wing-muscles. We infer that the creature must have been a poor flyer. The wing ended in a tridigitate reptilian hand, armed with claws, showing that archæopteryx was a climber. Yet other reptilian characters were the shape of the vertebræ, the long tail which resembled that of a lizard and consisted of twenty distinct bones, the fewness of the pelvic vertebræ, the fact that the pelvic bones had not coalesced, the imperfect coalescence of the wrist and metacarpal bones, and the possession of teeth.

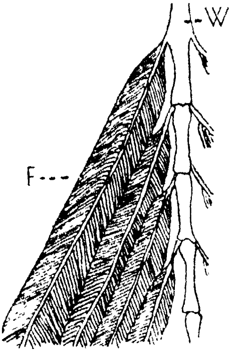

FIG. 9.—PART OF THE TAIL OF ARCHÆOPTERYX.
W, caudal vertebra ; F, feathers.

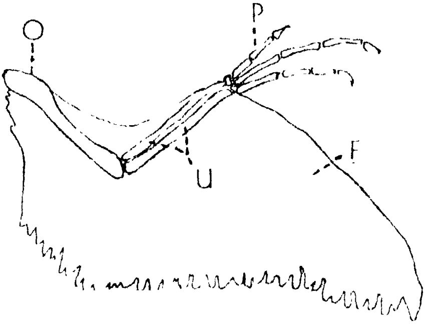

FIG. 10.—WING OF ARCHÆOPTERYX.
O, arm-bone ; U, the two bones of the fore-arm ; P, finger ; F, sketch of the wing.

B.—The discovery of these two specimens was certainly a great advantage to the theory of evolution. Are there other transitional forms, which, until found, were " missing links " ?

A.—Certainly ; and among extant creatures as well as among fossils. In the Permian there are reptiles which in general aspect and in numerous structural details are very like the lower mammals. In the next superposed strata, those of the Trias, we come upon the first vestiges of marsupials.

B.—Then you say that there exist to-day links between phyla of widely divergent kinds. How is that explicable ?

THE ZOOLOGICAL SYSTEM

A.—Have you ever considered upon what our zoological system—the classification of animals in species, genera, families, orders, classes, and phyla—is based ? What is the object of this systematisation ?

B.—I suppose it is based upon degrees of kinship. The significance is that of a library catalogue, in which the subject-index reduces chaos to order, and helps us to make a general survey of the contents.

THE CONCEPT OF SPECIES

A.—You have reached the root of the matter. We class as one species all animals which pair and produce fertile offspring. Creatures which are incapable of pairing and procreating fertile offspring, but otherwise resemble one another closely in morphological and physiological characters, constitute a genus. For instance, heathcock and mountain cock will pair, and the fertilised eggs will hatch out, but since the resulting birds are sterile we regard heathcock and mountain cock as distinct species. In like manner, mules are the offspring of a union between a jackass and a mare, or (less often) between a jinnyass and a stallion. The mules can copulate, but are barren, so we reckon the horse and the donkey as two different species. But the various individuals belonging to the same " good " species may differ greatly in appearance. Think of the varieties of pigeon, of domesticated dog, and of the human race. But human beings of different colours and " races ", dogs of all breeds (unless there are mechanical obstacles due to great differences in size), and various sorts of pigeons, can interbreed freely and produce fertile offspring, so these are three " good " species. (It is true that people often speak of the " genus homo ", but it is a genus containing only one species, Homo sapiens, and comprising all the " races " of man.) The wider classifications into genera, families, orders, classes, subphyla, and phyla, is based upon the possession, in each case, of a diminishing number of common characters. Thus the system corresponds, as it were, to a natural genealogical tree. Still, zoologists do not suppose that from this point of view their classification has more than an approximative worth. No one imagines that phylogenetic evolution took place in the precise order and along the precise ramifications represented by the classification. The gaps in our knowledge are far too many and too large for the establishment of a perfectly unobjectionable natural system of classification.

MULES AND OTHER INFERTILE HYBRIDS

NATURAL GENEALOGICAL TREE

Well now, there are certain species which cannot easily be pigeonholed in our classification, because they present characters belonging to widely separated branches of this genealogical tree. The inference forces itself upon us that, at a time when the two now divergent branches were conjoined, such a species must also have originated from the common stem, and that they have (perhaps owing to geographical isolation) preserved some of their primitive peculiarities.

B.—Then we may suppose archæopteryx to have been the progenitor, on the one hand, of the extant reptiles, and, on the other, of the birds ?

PEDIGREE OF THE AVIAN STOCK

A.—That would be an erroneous conclusion. All we are entitled to infer from the existence of lizard-like characters in archæopteryx is that this organism must have been an early shoot from the great reptilian stem ; and from its avian characters we infer that it is closely akin to the birds. Its relationship to the reptiles is obviously that of a peculiar lateral shoot consisting of creatures that became adapted to an aerial life, while the main branch continued its development towards the modern snakes and lizards. We are not even sure that archæopteryx was a direct ancestor of our own birds. All we can say with confidence is that, if this is not the case, archæopteryx and bird must have had a common ancestry in the Middle Age of the earth. At most we are entitled to suppose that certain families of modern birds may have sprung from archæopteryx, while the subclass of the ratitæ or (comparatively) wingless birds—comprising the ostriches, the cassowaries, the emus, the kiwis, etc.—probably sprang from another group of primitive reptiles.

B.—I thought that all the species of any phylum had a common ancestry.

ONE OR SEVERAL LINES OF DESCENT ?

A.—Here you touch upon the difficult and still debatable problem of the monophyletic (one-branched) versus the polyphyletic (many-branched) origin of the organic world. I will not attempt to go deeply into the matter, but will content myself with expounding my own view—for which I can advance at least as good reasons as the advocates of a monophyletic evolution, who believe the animal and vegetable world to have been both derived from one primitive ciliated organism which was neither animal nor plant. If we assume the

SPONTANEOUS GENERATION

occurrence of spontaneous generation to have been the origin of life on earth, and think ourselves back into those distant days when the cooling world arrived at a chemical and physical condition in which (through a fortunate conjuncture of carbon and nitrogenous compounds) the most primitive living creatures could come into existence, does it not seem probable that such conjunctures may have occurred simultaneously at various parts of the earth's surface ? Since in those remote times conditions were not identical all over the world, since there were already tropical, sub-tropical, temperate, sub-arctic, and arctic zones, it may be supposed that the aforesaid conjunctures will not have been everywhere the same, and that there must have been slight differences between the primitive organisms and in the constitution of the protoplasm on which their life depended. It is thus perfectly conceivable that these different primal living creatures, forming themselves under slightly differing environmental conditions, may from the outset have pursued a different evolutionary course, and thus have become the ancestral stocks of the various animal and vegetable phyla now extant. At any rate there is a good deal which may lead us to suppose that animals and plants have sprung from different roots.

B.—I had come to some such conclusion on my own account. But you were going to tell me about other transitional forms, not fossils, but some that now exist.

PERIPATUS

A.—I will give you a typical example. In three widely separated regions, namely in Cayenne, South Africa, and New Zealand, there is found a small creature about four inches long, peripatus by name. Outwardly it resembles a millipede. Notwithstanding its commonplace aspect, its discovery gave rise to a lively scientific controversy, because it could not be fitted into any of the recognised phyla of the animal kingdom, its body exhibiting a strange mingling of the characters of the segmented worms (annelids), and those of the spiders, crustaceans, millepedes, and insects, which make up the sub-phylum of the arthropoda. Thus in peripatus we are reminded of the annelids by its possession of a genuine segmental organ such as is never found in typical forms in arthropods.

SEGMENTAL ORGANS

B.—To interrupt you for a moment, what are " segmental organs " ?

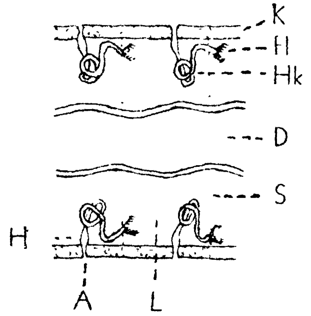

FIG. 11.—SEGMENTAL ORGANS OF AN ANNELID.

K, body-wall ; Fl, ciliated infundibulum ; Hk, urinary canaliculus; D, alimentary canal ; S, septum between two adjoining segments ; L, body-cavity ; H, urinary bladder ; A, orifice of the urinary bladder.

A.—Segmental organs or urinary canals or nephridia are the excretory organs of the cœlomatous worms, and are most typically developed in the appendiculated ringed worms or annelids. They perform the function of the kidneys of higher animals. Each segment has a pair of nephridia opening within into the cœlom or body-cavity by a funnel-shaped ciliated aperture (infundibulum) and, through a much-convoluted tube, they debouch on the outer surface of the body by an aperture known as the uropore. Just before the uropore this excretory duct expands to form a sort of urinary bladder. Thus in their structure these nephridia remind us of the tubules of the Wolffian bodies or primordial kidneys of vertebrates. The kinship of peripatus with the articulata, and especially with the insects, is shown by its possession of a tracheal system for respiratory purposes. This consists of long, unramified, air-containing tubes which arise by ingrowth from the surface of the body. Above all, the existence of jointed though very simple extremities resembling the chætæ or setæ (parapodia) of marine chætopods, indicates a close kinship with the articulata. We are, therefore, justified in assuming that peripatus diverged early from the annelid stock, and that just as primordial birds and reptiles had a common ancestry so also had

ADDITIONAL CONNECTING LINKS

peripatus and the insects. Furthermore we know of a number of additional connecting links between the worms and the other phyla of the animal kingdom. Thus, balanoglossus is a transitional form between worms and echinoderms; and the lancelet, the much-discussed amphioxus, is transitional between worms and vertebrates.

B.—I should like to learn much more about the animal life of the prime.

A.—Read Othenio Abel's admirable *Lebensbilder aus der Tierwelt der Vorzeit*, or the same author's *Paläobiologie und Stammesgeschichte.* But I will myself add a little to the brief sketch I have already given.

THE CRETACEOUS

As previously said, the first unmistakably birdlike creature was found in the Jurassic. Then, in the Cretaceous, we encounter true birds—hesperornis, for instance, which was about the size of a stork, but shaped like a penguin. Hesperornis, however, was distinguished from modern birds by having teeth, and even successive sets. After

HEY-DAY OF BIRD DEVELOPMENT

the Cretaceous, the species of birds become far more numerous.

TITANIC FORMS

Among them are giants, such as Dinornis giganteus, a bird of ostrich build with powerfully developed legs but with its brachial bones almost completely atrophied. It was nearly eleven feet high. Still more gigantic was the kindred moa, which survived in New Zealand until well on into the eighteenth century. Moas were the principal game hunted by the Maoris, Polynesian immigrants to New Zealand a few hundred years ago. Many investigators believe that it was the extinction of the moas which led the Maoris to the practice of cannibalism. Eggs of this huge bird, eggs having a circumference of more than a yard, are still found from time to time to-day. An allied extinct species of wingless bird is æpyornis, whose bones and eggs (having a content of nearly two gallons) are found in the swamps of Madagascar. It will interest you to know that fossilised bones of the African ostrich are often found in Europe in the Diluvial strata.

B.—The climate of our continent must have been much warmer then.

A.—Certainly. In the course of the history of the world there have been numerous transitions from hot to cold and from cold to hot in the European climate. Let me add, in conclusion, that from the time of the Trias onwards the mammals as well as the birds

RISE OF THE MAMMALS

come to play a more and more important part in the zoological scheme, and the types resemble our contemporaries more closely. But it is time to bring our journey through the ages to an end.

FOURTH EVENING

RHYTHM OF LIFE

Adaptational Lines or Lines of Descent

B.—At the beginning of our talks, you spoke somewhat contemptuously of genealogical trees. Yet it seems to me, in view of what you have told me about transitional forms, that it ought to be possible to draw a fairly trustworthy genealogical tree of the animal world.

A.—Possible and useful, if we keep in mind the hypothetical character of such a genealogical tree. Of more evidential value than one great tree of the animal kingdom is the drafting of restricted adaptational lines or lines of descent. The palæontological diary of the world supplies us with data requisite for the construction of many such limited genealogical trees. Take, for instance, the pond-snails or mud-snails, paludinidæ, whose abundant remains in the tertiary deposits of Slavonia, the island of Cos, Croatia, Southern Hungary, and Rumania enable us to construct an almost flawless genealogical tree. The paludinidæ are characterised by a great variability in their shells. In the oldest strata we find paludinidæ with smooth shells having flattened coils. In superposed strata, the shells become taller, and are even more richly ornamented. If we were only acquainted with the ancestral form Paludina neumayeri and the recent form Paludina hoernesi, we should regard them as having no more than a very remote kinship. It was the discovery of numerous intermediate types which showed that the former had developed into the latter.

Line of Descent of the Pond-Snail since the Tertiary Epoch

Reasons for Modification

B.—What is the explanation of these changes? Modification in the conditions of existence, I presume?

A.—The cause is supposed to have been a gradual diminution in the brackishness of the water in which paludina originally lived.

B.—In this case, then, we have unambiguous evidence of the transformation of one species into another?

A.—Beyond question. Unfortunately, however, such complete cycles of evolution are known only in the case of small groups of animals, and concern species only, not wider classificatory departments.

B.—Can transformations of the kind be ascertained to have occurred in species of the higher animals, and ones better known to those of us who are not biological specialists ?

Pedigree of the Horses

A.—Yes. As, perhaps, you are aware, horses, rhinoceroses, and tapirs are classed together in the sub-order of perissodactyla (odd-toed animals), the weight of the body being sustained chiefly (in horses, exclusively) by the middle toes, the lateral toes being more or less completely atrophied.

B.—Then the horse's hoof corresponds only to the middle toe ?

A.—Yes ; in the case of the fore feet to the middle " fingers ", and of the hind feet to the middle toes, these fingers and toes being very strongly developed. All the other fingers and toes of a horse

Splint-Bones

are atrophied to become the insignificant splint-bones. If we compare the front leg of a horse with the human hand, we see that the splint-bones represent the vestiges of the index and ring fingers. Tapirs, however, have preserved four well-developed toes on the front legs and three on the hind legs. In rhinoceroses there are only three well-developed toes both on fore legs and hind legs. It is mainly this difference in the extremities which compels us to class horses, rhinoceroses, and tapirs in three distinct families of ungulates. Lucky finds in the Tertiary strata of Europe and America have shown, nevertheless, that all the modern species of equus derive from an ancestral form which had a far completer set of bones in both fore limbs and hind limbs, and also in other respects resembled tapirs.

B.—That is amazing ! What did these ancestral horses look like ?

A.—The oldest known ancestors of our horses, whose fossils have been excavated from the undermost strata of the Eocene, were about as large as a fox. They are classed in the genus hyracotherium. It is clear that they lived in large troops. As with tapirs, their anterior limbs had four well-developed toes, and their posterior limbs three. In the younger strata of the Eocene, hyracotherium gives place to the three-toed palæotherium, an animal about as large as a pony, and resembling a cross between a tapir and a rhinoceros. Next, in the oldest strata of the younger Tertiary, we find mesohippus ; and in superjacent strata of the same formation, anchitherium. These forbears of our modern horses also had three-toed extremities, but the middle toe of each foot was more strongly developed than the lateral toes, and bore most of the animal's weight. The atrophy of the second and fourth fingers and toes is still more marked in hipparion, whose fossils derive from the most recent Pliocene deposits of the Tertiary. Hipparion is already assuming typical equine characters. It is chiefly distinguished from the horses of our own day by its more slender build and smaller size ; also by having better formed vestiges of the lateral toes, though the accessory hoofs did not touch the ground. These primitive horses lived in large troops and were widely distributed over the surface of the earth, fossil

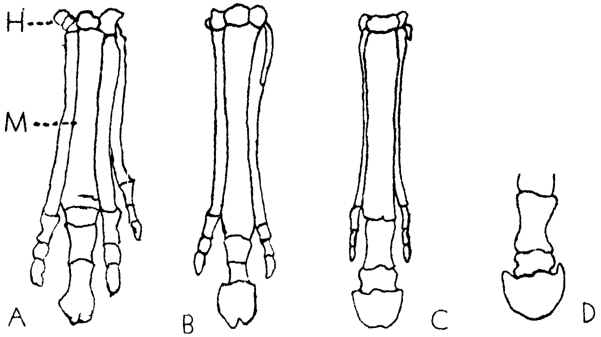

FIG. 12.—EVOLUTION OF THE FEET IN THE EQUINE STOCK.

A, fore-foot of hyracotherium (eocene) ; B, of mesohippus (lower miocene) ; C, of hipparion (pliocene) ; D, of extant horse ; H, carpal bones ; M, middle toe ; G, splint-bone.

specimens being found in the Tertiary deposits of Europe, Asia, Africa, and North America. The nearer we approach to the present time, the more marked is the atrophy of the lateral toes and their metacarpal bones, until at length they remain merely as the thin and vestigial splint-bones.

B.—That is certainly a very striking instance.

CHANGES IN THE TEETH

A.—Wait; I have not finished yet about the pedigree of the horses. It has not merely been the bones of the legs and the attached toes which have undergone secular changes, but likewise the teeth. The short and fanged teeth of anchitherium were gradually modified into the long and fangless prismatic teeth of the modern horse. If a sceptic remains unconvinced by the palæontological data, other evidence can be adduced.

B.—I am eager to hear it.

ATAVISM

A.—Sometimes foals are born with one or two well-formed supernumerary toes on the fore legs or hind legs. Such relapses into earlier phylogenetic stages are termed atavism. In one of our future evening talks I shall tell you of a number of similar happenings.

B.—Had not man already appeared in the Tertiary epoch ?

SPECIALISED EVOLUTION

A.—Yes; but before I go into that matter I want to draw some general conclusions about what we have previously discussed. If you take a wide survey of palæontological data, you will recognise that evolution has tended towards a gradually increasing specialisation, a more and more marked adaptation to particular conditions of existence. This specialisation has often become so extreme that, when a change in the conditions of existence has occurred, these unduly specialised creatures have become extinct. As I showed you in the case of the turtles, evolution is not reversible, for, at most, a phylogenetically lost organ can be substituted out of new material.

Law of Increase in Size

We can also deduce from the history of life on the earth that, just as the larger forms of living organisms, both animal and vegetable, have developed by degrees through the aggregation of minute primordial cells, so this law of increase in size applies to individual species that are in course of progressive development, until, in the most flourishing era of the creatures concerned, gigantic specimens are produced. Such a blossoming time, whose duration may vary a great deal from type to type, is often followed by a decline, which is usually attended by a reduction in size. You will also have noticed that, whereas many species remain true to type throughout almost interminable geological epochs, others undergo extensive transformation in comparatively brief periods. Especially when we trace the evolutionary history of certain of the smaller groups of animals do we find a very interesting law at work. Almost invariably, three phases present themselves. When a new group of animals is in course of formation, we note exceptional modifiability of form and inconstancy of organisation. We might speak of this primordial phase of rapid change as the experimental stage. Suddenly (one might almost say), there appear numerous unprecedented forms, which, however, do not exhibit a tendency to evolve in any specific direction. Often we note relapses. Many of the new forms disappear from the stage, to join the ranks of extinct species. By degrees, however, some of the new types become more constant. What had been a purposeless evolution has become purposive, as if striving towards a definite goal. In technical language this is spoken of as orthogenetic modification of the type.

Blossoming and Decline

Modifiability of Form

Experimental Stages

Purposeless and Purposive Evolution

B.—It seems to me that the coiling of the shell of the Silurian cuttlefishes is a good instance of this.

A.—Excellent. I am glad you have noticed that. This equable evolution towards a goal, this stressing of a form once achieved, is often maintained throughout lengthy periods of the world's history. Then a third phase is noticeable. Tendentious evolution seems to overshoot the mark. A structure which had small beginnings, and which up to a reasonable size was useful, becomes so large as to be a danger to its owner. A good example is afforded by Cervus or

Megaceros (The Irish Elk)

Megaceros giganteus, the Irish elk, which stood six feet high at the shoulder and had palmate antlers of enormous size, weighing as much as a hundredweight and sometimes measuring eleven feet between the tips. It is not unlikely that the possession of these stupendous ornaments was a contributory cause of the animal's becoming extinct.

Evolutionary Aberrations

Sometimes, however, in this third phase, purposive evolution comes to an end. Constancy of form is replaced by uncertainty of form. Ancestral traits crop out inharmoniously. Such evolutionary aberrations lead to an ever plainer degeneration, and ultimately to the extinction of the species. The cephalopods of the Trias are remarkable for this. In that geological formation, their shells assume a more and more complicated appearance and have unmeaning embellishments. At the same time their equable coiling passes more and more into abeyance. Their death-knell has sounded.

Architectural Parallels

B.—What you have just been saying about the three phases of organic evolution is strangely paralleled in architecture and some of the other arts. Here, likewise, we note, to begin with, a seemingly purposeless experimental stage. All possible forms arise and disappear, until a classical type gradually emerges. In the second phase, this develops " orthogenetically ", purposively, to a greater extent than the practical needs of the situation demand. Thus a climax of perfection is achieved. Then, as if the architects were dissatisfied with the acme of purposiveness and beauty, there ensues a period of unmeaning and excessive embellishment. The pure forms of the classical era are marred by superfluous ornamentation, until this phase culminates in a widespread evolutionary aberration and an unmeaning revival of antique forms (decorated period). In the history of life, this leads to the extinction of the species concerned ; in the history of art, to the decay of that particular style. Thus out of attempts at the making of a tall roof-support with materials chosen haphazard, there gradually developed the practical, purposive, and beautiful Doric column, which then tendentiously developed into the Ionic column with its elegant scrolled capital, and subsequently into the Corinthian column which already exhibited signs of decadence. The over-ornamentation of the entablature manifest in the Corinthian style went farther, to end in complete degeneration. But, to my way of thinking, the parallelism with organic evolution is yet closer. Think of nineteenth-century architecture. Classical types, beautiful in themselves, and significant in their original use—the styles employed in Greek temples and medieval cathedrals—were arbitrarily applied to the embellishment of buildings intended only for profane uses. Even so, some of them were viable and fine imitations of ancient buildings. At length, however, all feeling for style disappeared, and the result was chaos. But even as Nature the architect does not allow herself to be discouraged, and is continually making fresh ventures ; even as after the exaggerated evolution and the subsequent extinction of the giant saurians, she developed birds and mammals from the same root in new beauty and purposiveness, so likewise man's creative spirit is unconquerable and indefatigable. The meaningless classical decorations, the traditional revivals, were removed from the fronts of the huge over-ornamented blocks of flats, and were replaced by simple and unpretentious forms. Simplicity triumphed over sophistication, and architecture became once more adapted to its functions. But this sobriety denoted no more than a fresh start, and led (with a strict maintenance of purposiveness) to such a practically useful building as—to name one only—the Chile House in Hamburg, convincingly beautiful and deserving to be called classical in its outlines and its proportions.

Beauty and Purposiveness

A.—You have been giving me a very interesting discourse on æsthetics. I think your idea is worth following up. Perhaps this parallel can be subsumed in a wider law. It seems to me that beauty of form and purposiveness or suitability are always closely related. Archæopteryx, the primordial bird, with its cleavage of characteristics (half reptilian in its first groping adaptation to aerial life, and half avian), would certainly have appeared hideous to us ; whereas a soaring eagle, an albatross or a seagull following a ship, is a paragon of technical perfectionment in its adaptation to flight, and therefore seems to us beautiful. In like manner the first locomotive, Stephenson's " Rocket ", which was like a saucepan mounted on a truck, is both ludicrous and ugly. But with technical perfectionment came beauty, so that the modern locomotive, perfectly adapted to its functions, appeals to our æsthetic sense. Here, as in other fields, the classical epoch arises out of storm and stress ; then comes romanticism with its first signs of decadence ; these increase, until we are justified in speaking of evolutionary aberrations ; and at length complete decay and destruction ensue—unless in one of the ostensibly decadent types a fresh impetus starts, leading in course of time, through purposive evolution, to the production of new, different, and vigorous forms.

Phases of Evolution

B.—Since, as you have told me, these three phases of evolution occur, not only in cephalopods, but also in other classes of animals, it certainly seems probable that they are manifestations of a general law.

A.—We are still in the realm of hypothesis here. Beurlen, however, recently gave a luminous explanation of the phenomena in question. The matter is certainly interesting, and demands closer investigation.

B.—I wish you would give me an outline of Beurlen's views.

Genealogy is a Chain of Individual Developmental Links

A.—If you contemplate the genealogy of any phylum or branch of the organic world, if you study phylogeny, you will see that it does not consist of a succession of adult individuals, but of a chain of individual developmental links. The defectiveness of the palæontological record is, in Beurlen's opinion, due, not so much to inadequacy in the preservation of types that have become extinct, as to the impulsive appearance of new types. There is much evidence to show that living creatures during their embryonic phase, when their cells are less differentiated and therefore more plastic than those of adults, react more readily than do these to environmental stimuli and thus

CORRELATION OF GROWTH

can easily be modified. " Owing to the correlation of growth, very slight changes in the moment at which the rudiment of some particular organ is formed, or in the speed of its development, can lead to marked deviations from type in the adult."

B.—Wait a little, please. What am I to understand by " correlation of growth " ?

A.—The mutual dependence among an animal's organs ; the fact that changes in one organ of the body affect the other organs and produce changes in them. You will learn more about this by and by. To give you an instance now, a slight change was needed in

CHANGES IN EMBRYONIC DEVELOPMENT

the development of the reptilian mandible (lower-jaw bone), a modification in its articular portion, to fit it for mammalian uses. This was necessarily associated with a change in the bite, and a consequent transformation of the masticatory muscles, involving changes in the whole skull and entailing transformations in numerous other organs. The animal thus produced was, when adult, of a very different type from the ancestral reptile, and seemed to have originated abruptly.

SUDDEN APPEARANCE OF NEW TYPES (MUTATIONS)

In other words, a change in the influences that affect the embryo or the youthful organism may cause what appears to be an impulsive change of type, may lead to a " mutation ". Thus the new adult organism comes to differ widely in aspect and organisation from its progenitors. We have experimental proof that a change in embryonic development can be brought about by physiological stimuli. That is one way of accounting for the origin of new types impulsively, so to say ; for the occurrence of mutations. Presumably modifications in individual development are especially apt to take place when a comparatively undifferentiated type is, owing to geological revolutions, exposed to rapidly changing conditions of existence. " Mutation," writes Beurlen, " the appearance of new types by leaps and bounds, is the outcome of the reciprocal interaction of organism and environment during ontogenetic [individual developmental] growth." Since

DEFECTIVE ADAPTATION

the changing stimuli act most powerfully in early embryonic life and are at first undirective, there are produced adults having extremely diversified forms, and very imperfectly adapted to the new conditions. A large proportion of the resulting types are so completely unsuited to their environment that they speedily die out ; only a few of them can make good and undergo further development.

" The formation of new types in the explosive evolutionary phase ", or, as I have called it, the experimental phase, " is thus purposeless, independent of immediate adaptation ; it is solely determined by the way in which a particular organism reacts to particular environmental stimuli ". Consequently, the adult of the newly formed type, being imperfectly adapted to the extant environment, must seek out a more suitable environment, under pain of extinction.

Dominance of Form

In this opening phase, therefore, form is dominant over function, prescribing the environment in which the organism can survive. But when the newly originated type has succeeded in finding a suitable environment and remains capable of further development, the relationships are reversed.

Dominance of Function

Inasmuch as, in the history of the world, a change in the conditions of existence usually takes place very slowly, identical stimuli continue to work in like manner upon all the individuals of a species for a long series of generations, prescribing for the organism some particular mode of life. A uniform mode of life and uniform stimuli naturally work in a uniform direction upon the structure and shapes of the organism, and gradually give a definite direction to its evolution. There " crystallise out ", as one might say, particular forms which are continually better adapted to the conditions of existence, since in the long run the defective types are eliminated because they are unsuccessful. This signifies that function has now become predominant over form or structure. Assuming that the geological conditions remain unchanged, adaptation to a particular area and a particular mode of life will tend towards perfection. At the same time, however, with increasing specialisation, the range of evolution and the capacity for further evolution steadily diminish. The type grows more rigid, and seems to have become permanently fixed.

Restriction of the Potentialities for a Successful Existence

Such a one-sided development leads in course of time to a formidable restriction of the potentialities for a successful existence. Here, too, to use a showman's phrase, " what is gained on the swings is lost on the roundabouts ". A salmon can migrate up-river from the sea ; a herring, which is specialised for life in salt water, would perish if it tried the experiment. I have given you several examples of the way in which such a purposive and highly specialised evolution is apt to lead to an unduly close adaptation, to an overshooting of the mark, and to consequent extinction of the type. Obviously the forms that are most closely adapted to particular conditions will be more likely to perish when these conditions change than will the forms that are less differentiated and more variable, and can therefore better adapt themselves to a changing environment.

B.—How do you account for the fact that evolutionary aberrations sometimes occur in types which have been long and intimately adapted to their environment ?

A.—Although the record of the rocks shows that what you speak of does happen at times, our present knowledge does not enable me to answer your question. The explanation still eludes us.

DURATION OF GEOLOGICAL EPOCHS

B.—Please answer one more question, and then I will not worry you further to-day. How long did the various geological epochs last ?

A.—As you can see in the table, their duration differed. The Cambrian formation represents a period of seven hundred million years or more. Silurian, Devonian, Carboniferous, and Permian taken all together, occupied about three hundred million years. What I have called the Middle Age of the earth, comprising Trias, Jurassic, and Cretaceous, is reckoned to have lasted one hundred and forty million years. The most recent formations, Tertiary, Diluvium, and Alluvium, represent a period of round about sixty million years. You see, then, that, as we pass onward through the ages, the pace of organic evolution has increased. Herein we have another parallel in human affairs. Think of the extraordinarily rapid advances in science and technique during the last hundred years.

ACCELERATED EVOLUTION

B.—I find it very hard to attach any clear meaning to such enormous periods of time.

A THOUSAND YEARS ARE AS ONE DAY

A.—Perhaps it will help you to picture them better if we reduce the scale. If we turn for purposes of comparison to the biblical account of the story of creation, remembering that Genesis speaks of the Six Days of Creation, and that in the New Testament we read " With the Lord, a thousand years are as one day " (2 Peter, 3, 8), and adopt the scale of Genesis, we shall find that the primal stage of the earth lasted three days, twelve hours, and fifty minutes ; that from the beginning of the Cambrian to the end of the Permian occupied two days and nine hours ; that the Middle Age of the earth lasted nineteen hours and four minutes ; and that the three most recent formations were laid down in six hours and six minutes. We may add thirteen minutes, representing the period since the last Ice Age, to make up the six days. Human history would comprise only thirty seconds.—Well, I will say good night now, for my head is buzzing, and I expect yours is in the same condition !

FIFTH EVENING

DEVELOPMENT OF MAN

Did Man already exist in the Tertiary ?

A.—After we have spent four evenings on a vast journey through space and time, after we have soared through the æons and wantoned in barely conceivable figures of duration, let us now turn to smaller things, smaller but not less important, and certainly no less enigmatic.

B.—You have, so far, said scarcely a word about what interests me most, about our own fossil ancestors and the first appearance of man on earth.

A.—Unfortunately this is a domain of knowledge in which facts are scanty, and are open to various interpretations. True, Cuvier's assertion that there were no fossil men has long since been refuted by numerous discoveries. Still, that is a thorny topic, for until recently it was one in which scientific judgment was obscured by *a priori* philosophical views and dogmatic prejudices. Hence the early history of mankind is full of errors and contradictions. Probably man existed already in the Tertiary, although no indisputable traces of Tertiary man have yet been found. Unobjectionable finds, whether of human bones or of primitive stone tools shaped and used by human hands, are all post-Tertiary. The find made in the year 1726, which was for a time supposed to have proved the existence of Tertiary man, ended in profound disappointment. The bones described as human by the Swiss naturalist Scheuchzer proved to be those of an extinct species of salamander. It need hardly be said that this blunder was a great source of strength to those who unhesitatingly maintained the thesis of the constancy of species.

Stone Tools as Evidence

B.—In the prehistoric collections exhibited in anthropological museums, there are many flint tools which date from the Tertiary.

A.—Experts still differ as to the evidential value of these alleged tools. Alfred Rutot, the Belgian archæologist, distinguished as regards such primitive utensils two periods, the early cultural level of the " pierres utilisées ", which derive from the Tertiary, and the later cultural level (more advanced) of the " pierres taillées ". Primordial man was not yet able in the early days to fashion such implements, and was content to use as weapons, as wedges, and as chisels or

Pierres utilisées at Pierres taillées

hatchets, flints which had been split by nature. These served his turn. Many anthropologists hold that fragments of flint from Tertiary deposits show plain traces of having been thus used by man—in which case man must have existed in the Tertiary epoch. Others dispute the supposed facts and reject the inference. But there is no doubt that the "pierres taillées" from the Quaternary were shaped by human hands.

Homo Heidelbergiensis

The earliest indisputable vestige of primordial man is the famous lower jawbone of Homo heidelbergiensis, which was excavated from a sandpit near the little village of Mauer, not far from Heidelberg. According to the investigations of various geologists, the site of this find belongs to what is known as the Günz-Mindel Interglacial Epoch, which is supposed to have been about half a million years ago. This maxillary bone is practically chinless, whereas the chin is characteristic of modern man, and is especially well developed in Europeans. Were it not for the teeth, which are unmistakably human, the Heidelberg jaw might be supposed to have been derived from an extinct species of anthropoid ape. As matters stand, however, the existence of a low type of Quaternary man is placed beyond doubt by this and other discoveries. But the naïve view that the extant anthropoid apes (gorilla, orang-utan, chimpanzee, and gibbon) are our direct ancestors or even near cousins has long since been discarded as erroneous. The extant anthropoid apes are not the first links of a developmental chain which has culminated in man, but the last links of a separate evolutionary series. From the morphological outlook, as concerns the structure of the extremities and the shape of the skull, for instance, the human body is of a far more primitive type than that of the anthropoids, so that there would be more justification

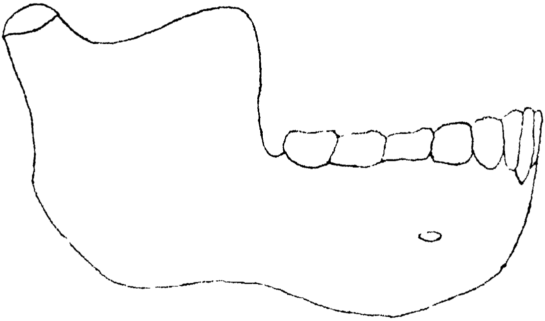

Fig. 13.—Lower Jaw of Homo Heidelbergiensis.

Ancestors of Man

Anthropoid Apes and Man Distinct Branches

SIMIAN AND HUMAN SKULLS

for the belief that the anthropoids have sprung from human ancestors than for the converse.

B.—You are joking, surely? I never heard anything more paradoxical.

A.—No, I am not joking. I cannot give you all the details which form the grounds for what I have just said; but I will ask you to look at this illustration showing three skulls, and to tell me which belong to the same species.

B.—Obviously, the two to the left.

THE GORILLA

A.—Wrong! The left-hand one is the skull of an adult human being; the right-hand one that of an elderly male gorilla; and the middle one that of a young gorilla. Whilst the skull of the young gorilla has many characters which make it resemble a human skull, that of the old male gorilla has assumed a bestial aspect through the development of prominent parietal and occipital crests, through the formation of well-marked superciliary ridges, through the projection of the cheek-bones, and through the forward protrusion of the jaws into a muzzle. Since, as you will learn in due course, ontogeny (individual development) is an epitome of phylogeny (the development of the stock), we may infer that the ancestors of the gorilla were more manlike in appearance than their descendants. Through adaptation to new conditions of existence these primordial gorillas became modified in a way which made them diverge more and more from the human type.

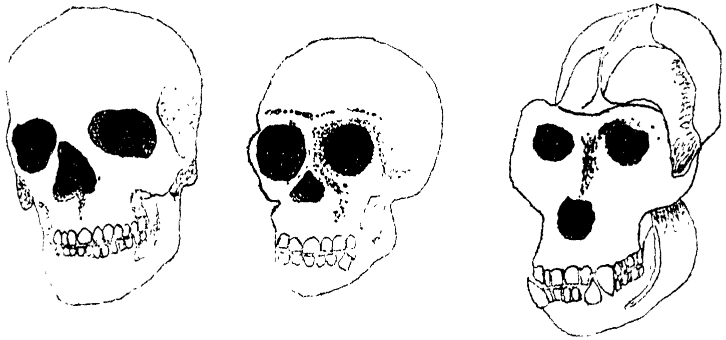

FIG. 14.—SKULL OF AN ADULT HUMAN BEING, THAT OF A YOUNG GORILLA AND THAT OF AN ELDERLY MALE GORILLA.

B.—What is the explanation of the remarkable formation of the adult gorilla's skull?

A.—It is connected with the animal's mode of life. The adult gorilla feeds mainly upon the hard parts of certain plants which need to be vigorously chewed with powerful molars. The long, sharp, and menacing canine teeth are used as weapons in fights between the males and as means of defence against beasts of prey. Powerful teeth need large and powerful jaws. The vigorous movements of mastication effected by these big jaws demand the growth of large and thick masticatory muscles, for whose attachment a smooth skull would not suffice. Hence the development of the parietal ridges. The skull, having become large and heavy, needs larger neck muscles for its support. These, again, require the occipital crest for their attachment. The youthful male gorilla, which, to begin with, is suckled by its mother and then lives for some years upon a fruitarian diet, and which is less combative than the adult, has no more need of these exaggerated bony ridges on its skull than has man with his weaker teeth and lighter cranium.

Half-Apes or Lemurs

B.—Is it true that human beings are descended from half-apes, from lemurs ?

A.—Proofs are lacking. It seems most likely that the ancestors of the human race must have branched from the mammalian stem very long ago. From this branch the lemurs, the monkeys and apes, and human beings may then have been successively and separately derived. Whether the spark of reason and self-awareness crystallised out from animal instincts concomitantly with the perfectionment of the human form, or whether a divine creative act has in this respect distinguished man from all other animals, is a matter concerning which science has no decisive verdict to give. The problem belongs to the realm of faith.

The Spark of Reason

B.—What you say is congenial to me. Human consciousness is so wonderful that modesty is appropriate when we reflect upon its origins. But please tell me more of what is known concerning prehistoric man, and what facts bear witness to his descent from lower animals.

Evolutionary Stages of Contemporary Human Beings

A.—If you study the human beings now alive, even a casual glance will show you that they are at very varying evolutionary levels in respect both of body and of mind. The Tasmanian blacks (the last pure-blooded Tasmanian died in 1876), curly-headed negroids, were shown by their skulls to be very low-grade human beings. Their mode of life was accordant. Nomadic hunters, they sheltered in caves or hollow trees, and their technical capacities were only sufficient to enable them to make rough-stone implements and weapons. The Tasmanians were, in fact, palæolithic human beings, belated survivals from the Old Stone Age. Again, the blubber-lips of the negroes, show them to be primitives as compared with the higher races, though they are farther advanced from the animal

Tasmanians

Blubber-Lips

3096

Weight of Brain

Mental Disorders in Negroes

stage than were the Tasmanians. Inferiority of intellectual capacity is also shown by a smaller weight of brain. The average brain-weight in Europeans is 1361 grammes; in negroes, 1316 grammes; in Tasmanians, Bushmen, and the Veddahs of Ceylon, ranging from 900 to 1200 grammes. Differences in the arrangement and complexity of the convolutions of the brain cannot with certainty be shown to exist as between various races of man. The rapid cultural development of the American negroes since their liberation might be regarded as an argument against the thesis that negroes stand at a lower evolutionary level than whites. Nevertheless, the rapid assimilation of western culture has been dearly bought. Whereas in 1870 there were only 367 lunatics among 1,000,000 negroes, during the next two decades the proportion increased nearly threefold, this being a sign that a growing percentage of the blacks broke down mentally in their endeavour to keep pace with the whites. Individual specimens of the negro races can, however, attain a very high intellectual level.

B.—Disregarding primitives, which race is most highly evolved intellectually?

Weight of Brain in Chinese

Cultural Level and Size of Skull

A.—That is rather a thorny question. We Germans incline to give the palm to the blond, blue-eyed Nordic race. But if we are to take average brain-weight as a criterion, the Chinese lead with 1428 grammes. Apparently brain-weight increases rather rapidly with increasing cultural development and a higher standard of education. The average brain-weight of brain-workers is in Europe greater than that of manual workers. The Chinese were highly civilised at a time when barbarism prevailed throughout Europe. Presumably this was owing to the greater average brain-weight of the Chinese. On the other hand there is a relationship between stature and brain-weight. For the rest, a high development of the intellectual faculties discloses itself more in an increase in the grey matter of particular regions of the cerebral cortex than in the absolute weight of the brain; but measurements of the cubic capacity of the skulls found in ancient barrows have shown that an increase of this has gone hand in hand with cultural progress.

Out-Sizes in Hats

B.—A hat-manufacturer of my acquaintance tells me that it does not pay him to make the largest sizes of cheap hats and the smallest sizes of expensive ones, since there is practically no demand for them in either case. This would indicate that in general the poor have smaller heads than the well-to-do.

A.—Pfitzner, who circularised the German hatters, learned the same thing from their replies.

European Races

B.—What about the various European races as regards this matter of brain-weight in relation to intellectual capacity ?

A.—The term " European races " is almost unmeaning, if we try to differentiate them in the biological sense of the word " race ". For thousands of years there has been so much racial intermingling in this part of the world that the various European countries have all become hotchpotches. There is no longer anywhere to be found a pure Teutonic, Latin, or Slav stock. Consequently there is no scientific possibility of classing these races as " higher " or " lower " respectively. For a time there seemed a hope that serological tests of affinity might enable us to ascertain the finer differences of race ; but now it appears that even the " blood categories " fail us in this respect. Let us return to the consideration of the remains of prehistoric man. As to the possibility of a deliberate breeding of higher types of human beings, we shall discuss that in connexion with our study of the laws of heredity.

Climatic Conditions in the Tertiary Epoch

B.—What climatic conditions prevailed in this part of the world at the time when man is believed to have appeared on earth ?

A.—In the early Tertiary, Europe had a tropical climate. We know this because palms, bananas, magnolias, fig-trees, and other plants of the torrid zone grew here. Then the mean temperature began to fall, until in the Miocene the climate became sub-tropical. At length, during the end of the Tertiary, the climate of Central Europe was probably much the same as it is to-day. In the Quaternary began the Ice Age, when large areas of Europe were covered by a compacted snowfield which temporarily stretched from Scandinavia across Holland, North Germany, part of the British Isles, and much of Russia. The Alps, too, were buried beneath icefields and snowfields from which extensions spread far into southern Bavaria. Many other regions, some even adjacent to what are now the tropics, were likewise visited by the cold of the Glacial Period. But there were several intermissions of this extreme cold during the Quaternary.

Coming of the Ice Age

Interglacial Epochs

The temperature rose, and the icefields receded northward to Scandinavia and southward to the high Alps ; then the cold returned, and the ice resumed its sway. In general we recognise five Glacial Periods. The first of these, known as the Günz Ice Age, began about six hundred thousand years ago. The second of these exaggerated " cold snaps ", a comparatively short one, was the Mindel Ice Age. The third, also short, is known as the Riess Ice Age. Next came the Würm Ice Age, which lasted about a hundred thousand years. After another transient period of warmth, came the last Ice Age, the fifth, like the second and the third comparatively brief, and ending with the Quaternary. The deposits that followed the Glacial Epoch in Europe are classed as Alluvium or Modern. They began about seventeen thousand years ago. During the Interglacial Epochs, animal and vegetable life reinvaded the regions from which the ice receded, and it is from these periods that the most important discoveries of prehistoric human remains date.

Beginning of the Modern Period of the World

Causes of the Glacial Epochs

B.—What are supposed to have been the causes of these Ice Ages ?

A.—We have no valid explanation as yet. Since the icefields spread simultaneously in Europe and in the tropics, many suppose that the cold must have been extra-terrestrial in origin, must have been due to changes in the sun. Others think of a shifting of the axis of the earth's rotation. Yet others invoke as explanation changes in the distribution of land and water in conjunction with variations in altitude. Whatever the cause, we know that there were Ice Ages also in the Pre-Cambrian period and in the Permian.

B.—I suppose that during these Ice Ages, Central Europe was as void of life as a desert ?

A.—Yes, wherever the ice-sheets extended. But between them were steppes and tundras, such as are found within the Arctic Circle to-day.

Climatic Conditions in the Interglacial Epochs

B.—You said that in the Interglacial Epochs living organisms effected a reconquest of the deserted regions. But was not the climate rather chilly even during these let-ups of the extreme cold ?

A.—To judge from the fauna and flora of such periods, the climate must have generally been warmer than our present one. The land was covered with huge forests, and both these and the steppes offered favourable conditions for abundant animal life.

B.—And the chief discoveries of prehistoric human remains date from the Interglacial Epochs ?

Neandertal Man

A.—Yes ; but important ones have come also from the Ice Ages. Homo heidelbergiensis, as I told you, belonged to the Günz-Mindel Interglacial Epoch. In the Riess Ice Age and the Interglacial Epoch that followed it, lived Neandertal man (Homo primigenius). Much nearer to contemporary man in their bony structure were the primordial men of the Würm Ice Age—the loess hunters or Aurignac men, and the reindeer hunters of the Cro-Magnon race.

B.—You stride through these things in seven-league boots. I should like fuller details.

A.—All right. I will begin with Homo primigenius, Neandertal man, who owes the latter name to the first discovery of his bones in the Neandertal near Düsseldorf. In the year 1856, some workmen digging in the Feldhofen Cave which was half filled with sand and loam, discovered the vertex of a cranium, two thigh-bones, a humerus, a radius, a collar-bone, and a number of skeletal fragments. Fortunately, Professor Fuhlrott of Düsseldorf was asked to examine this treasure-trove, and promptly recognised that the bones were those of a primordial man. Beyond question, many no less valuable finds have been ignored because no expert was available to save them from being thrown on the rubbish-heap. Probably but for Fuhlrott's intervention the Neandertal skeleton would have been disregarded, and an important chapter in the history of primordial man would have remained unwritten. True, science would have been spared an unedifying controversy. Fuhlrott's and Schaaffhausen's contention that the Neandertal bones were "the oldest memorial of the original human inhabitants of Europe" was fiercely criticised, nay ridiculed. All possible other sources than that of a "primigenial" man were suggested for the skeleton which had been lying for hundreds of thousands of years in the Feldhofen Cave. The original owner of this strange-looking and distinctly simian brain-cap must have been an idiot, a very old Dutchman, or a Cossack of Chernycheff's army! Even so outstanding an authority as Virchow joined the ranks of the adversaries. In a work published as late as 1872, he declared that the enormous superciliary ridges of the cranium and the other peculiarities of the bones were pathological, caused by disease in the lifetime of the individual, and without bearing upon human racial history. One thing which rendered the importance of the discovery of the Neandertal bones dubious was the impossibility, for some time, of ascertaining the geological age of the stratum in which they lay. After a while, however, in excavations close at hand, there were disinterred from the same stratum bones of the woolly rhinoceros, the cave-bear, and other Diluvial beasts, these showing that Homo primigenius had lived in the Quaternary period. A few decades later there were discovered at the entrance of a cavern in the chalk, at Spy in Belgium, two other skulls exhibiting almost identical characters. Kindred human remains about whose geological antiquity there could be no dispute were found at Krapina in Croatia, at Le Moustier on the right bank of the Vézère, at La Chapelle-aux-Saints in the department of Corrèze, and elsewhere.

Disputes about the Importance of the Neandertal Finds

Virchow's Standpoint

B.—What is there so remarkable about the Neandertal skull?

A.—It is typically dolicocephalic (long-headed as opposed to broad-headed). We are at once struck by the receding forehead and the before-mentioned strongly developed superciliary ridges which project above the orbits and run together in the middle line. They give the skull an exceedingly simian aspect, so that T. H. Huxley said it was the most ape-like human cranium yet discovered. In none of the extant races of man are the superciliary ridges developed to anywhere near the same degree, and they do not meet in the middle line. Nearest to Neandertal man in this respect are the Australian blackfellows, who have well-marked superciliary ridges, but their foreheads are less receding.

B.—Perhaps the Neandertalers were not human at all, but belonged to an extinct species of anthropoid apes ?

A.—The cubic capacity of the skull is too great for such a hypothesis to be acceptable. Besides, the other parts of the skeleton are distinctively human, and so formed as to show that Neandertal man walked erect. Even more excitement than was aroused by

Trinil Man

the Neandertal find, followed the discovery made at Trinil in Java during the year 1891. The finder, Dubois by name, a Dutch army surgeon, discovered, in an excavation on the left bank of the Bengawan River, a thigh bone, two molar teeth, and the upper part of a skull. These he considered to be the remains of an extremely primitive man, slain by a volcanic eruption, since the bones were found in lava. He called the creature " Pithecanthropus erectus ". The brain-cap was more simian than that of Homo heidelbergiensis, and might be supposed to have come from the skull of a huge chimpanzee. But the inclination of the lower part of the occipital bone (the part that gives attachment to the muscles of the neck), and the magnitude of the cranial capacity, vetoed this notion. The teeth were not sufficiently characteristic to be assuredly classed as human on the one hand or simian on the other, but the thigh-bone was typically appurtenant to our own genus homo. The teeth and the skull were found together, the thigh-bone a few yards away a year afterwards, so that it was possible that the remains were not all derived from the same creature. On the whole, however, " Pithecanthropus erectus " has been accepted as an early type of man, and by some has been rechristened Homo javanensis. He was for a time regarded as a Tertiary man, but closer examination of the deposits has shown that Homo javanensis must have been contemporary with Homo heidelbergiensis—Quaternary that is to say.

Early Human Remains in China

In December 1929, parts of an early human or sub-human skull and a well preserved lower-jawbone (having affinities to the jawbone of Neandertal man) were found at Chow-Chow-Pin in China—therefore called " sinanthropus " (Chinese man). In contrast with extant human beings, the foramen magnum of the occipital bone in sinanthropus was much farther to the back, leading us to suppose that he walked with his head bent forward. The jaws projected forward so much that he must have had something resembling a muzzle.

The Rhodesian Finds

In 1921 came tidings from Northern Rhodesia of the discovery of a skull very like that of Neandertal man. Maurer's researches led to the surprising conclusion that the extinction of the race to which this man belonged must have occurred very recently, for there was a gunshot wound in the bone. Unless the specimen in question was strongly atavistic, we must infer that descendants of the Neandertal race have lived on in Africa almost unchanged until the present time. Homo rhodesiensis had superciliary ridges heavier than in any existing human beings, and a brain which to-day would be definitely subnormal.

Oldoway Man

Next I must tell you of an important find made in the year 1913. This was in the northern part of what was then German East Africa, in Oldoway, a region up till then almost unexplored. The skeleton, in a fair state of preservation, was in a peculiar crouching position, and was sent to Germany by Reck, together with the masses of stone in which it had been found. Reck from the first contended that the remains were those of a Middle Diluvial man, but his views were sceptically received. The skull of the Oldoway man indicates high intellectual development, and reminds us of some of the ancient Egyptian skulls. It seemed probable, therefore, that the skeleton had only found its way into this Middle Diluvial stratum by chance. Further excavations in the neighbourhood have, however, confirmed Reck's view, and have shown that, at the site of the find, the strata were absolutely undisturbed. It was not a case of interment of a fairly modern specimen of the human race. In adjoining excavations, at the same level, there were found more or less carefully worked stone celts and other stone implements, disclosing the cultural level of Oldoway man. These primitive tools and weapons correspond to the European finds from the early Ice Age.

B.—I am very much confused. On the one hand, the Rhodesian skull appears to have the characters proper to Neandertal man, but the owner of the skull is supposed to have been almost contemporary with ourselves ; on the other hand, the Oldoway man, whose skull resembles that of the ancient Egyptians, is supposed to belong to the Middle Ice Age. The data seem contradictory.

Two Diluvial Races

A.—The probable explanation is that in the Diluvial Epoch there must have contemporaneously existed two very different races of man : the Neandertalers, who were at a low-grade intellectual level, and were not capable of higher development, but scattered groups of whom have survived into our own days ; and a higher race, whose skull resembled that of Homo sapiens as we now know him. The extant " races " of man developed from this latter stock. If the Oldoway find has been rightly interpreted, if the human skeleton found in German East Africa really dated from the Middle Diluvial Epoch, one may suppose that (scanty though the evidence is), the roots of man reach back beyond the Tertiary.

B.—I had never imagined that the origin of mankind was so obscure. We neither know at what geological date the first creature worthy to bear the name of man came into existence, nor from what part of the animal trunk man branched off.

DARWIN'S "MISSING LINK"

A.—Both these statements must be accepted without equivocation. The "missing link" Darwin hoped to find between man and his animal ancestors has not yet been discovered. Still (and this is the important point), we have direct evidence that in the Quaternary Epoch there existed creatures which, though unquestionably men, were of a primordial type when compared with ourselves. The law of evolution applies to the human race as well as to the lower animals.

MENTAL FACULTIES OF PRIMORDIAL MAN

B.—What is known about the intellectual capacities of primordial men? Can we picture to ourselves what they looked like and how they lived?

A.—Our chief guide to the intellectual powers of these primordials is the size of their brains, and this, in turn, is inferred from cranial

CRANIAL CAPACITY OF PRIMORDIAL MAN AND THE ANTHROPOIDS

capacity. If you contrast the profile curves of European skulls with those of the primordial skulls that have been preserved in the geological record, you will see without measurement that the cranial capacity (the cubic measure of the interior of the cranium) of modern man must greatly exceed that of his remote ancestors. In pithecanthropus the cranial capacity was round about 900 cubic centimetres; in Neandertal man, it ranged from 1300 to 1400 c.c.; in contemporary Homo sapiens, it runs from 1550 to 1750 c.c. We must not forget that the Neandertalers were of short stature, probably averaging about five feet. This must be allowed for in the comparison, for we are considerably taller. Even then, their brains were much smaller than ours.

B.—What is the cranial capacity of the extant anthropoid apes?

A.—In the largest specimens, it seldom exceeds 500 c.c.

B.—A notable difference! Apart from this question, I find it difficult to picture the aspect of primordial man.

WHAT PRIMORDIAL MAN LOOKED LIKE

A.—From the bones that have been preserved, we can with a fair measure of probability draw inferences as to what our remote ancestors looked like. Especially characteristic must have been the forward bending of the head, the great size of the muscles of the neck which were attached to occipital bony ridges, the prominent superciliary ridges, the wide separation of the orbits, the muzzle-like forward projection of the mouth, the prominent cheekbones, and the chinless lower jaw. Many investigators are inclined to connect the lack of a chin with the absence at this date of the power of articulate speech; but the idea that primordial man could not yet speak is, of course, purely hypothetical.

B.—Seeing that we are so ill-informed regarding the aspect of primordial man, I suppose nothing is known about his manners and customs ?

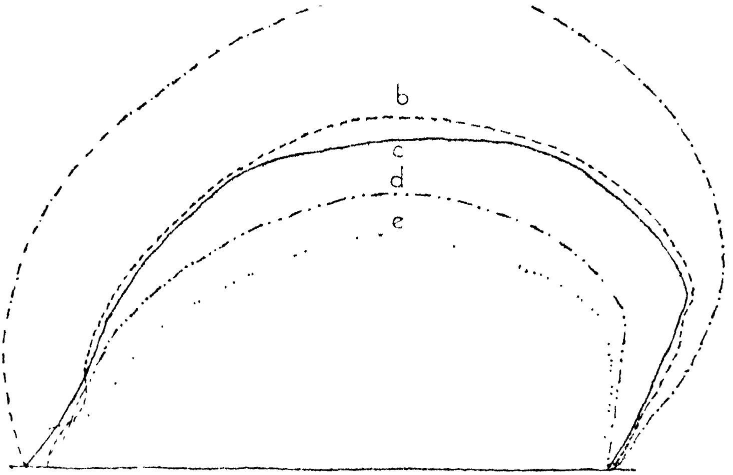

FIG. 15.—PROFILE-CURVES OF THE SKULL. (After DUBOIS.)
a, in a Papuan ; *b*, in the man of Spy , *c*, in Pithecanthropus ; *d*, in a gibbon ; *e*, in a chimpanzee.

MANNERS AND CUSTOMS OF PRIMORDIAL MAN

A.—It would be more accurate to say " little is known ". We can draw inferences from various finds. Thus it is plain that the Neandertalers were already acquainted with the use of fire. For instance, tree-trunks hollowed out by fire were found close to the skeletal remains at Spy. In the Krapina cave, there were broken and charred human bones beside the skeletons. This seems to

CANNIBALISM

indicate that some primordial men, at any rate, were cannibals. Since almost all the finds have been made in or near caves, we may

CAVE-DWELLERS

infer that these primordial men were cave-dwellers. Presumably, however, most primitives of the early days were nomadic hunters, using their stone weapons in the chase.

BEASTS OF THE CHASE

B.—What were the chief animals they hunted ?

A.—Probably formidable ones, since in the Quaternary period there were still huge mammals in Central Europe. Besides the mammoth (Elephas primigenius), with tusks more than twelve feet long, there was the largest of all the proboscidea, Elephas antiquus, the hairless two-horned Siberian rhinoceros (Rhinoceros antiquitatis), whose anterior horn was more than a yard long, and its still larger cousin, Rhinoceros mercki. On the steppes and in the forests there were large herds of Bos primigenius (the aurochs or European bison), and in the autumn the bellowing of the giant elks must have made the forests ring. Broken and charred bones show that primordial man was successful in hunting down all these great beasts. But his chief quarry was probably the reindeer, which in the late Quaternary had made its way as far south as Spain. The ancestors of our horses also lived in great troops in the Central Europe of those times, and were sedulously hunted.

TROOPS OF HORSES AT SOLUTRÉ

B.—How is it known that the horses were gregarious, and that primordial man hunted them ?

A.—At Solutré, not far from Lyons, a plateau ends in a precipice. At the foot of this inland cliff have been found thousands of equine skeletons, whose skulls had been artificially opened. The assumption is that primordial man drove troops of wild horses over the precipice and regarded the brains as a delicacy. Maybe, thousands of years after the Great War our descendants will find similar piles of horses' skeletons in the Innsbruck Valley or near Dünaberg—if man leaves nature to her silent task. There numbers of wretched horses died of starvation, and the bodies were speedily covered by sand and mud.

B.—Was Quaternary man attacked by beasts of prey ?

A.—Certainly. Many caves of the period are full of the bones of cave-bears, cave-lions, and cave-hyænas.

DOMESTICATION OF ANIMALS

B.—Did primordial man keep domesticated animals, and, if so, is anything known about the process of domestication ?

A.—The first part of your question is unanswerable. The history of our own domesticated animals is still in great measure obscure. In unsophisticated natural conditions, most animals are friendly. Even beasts of prey seek the vicinity of human beings, to feed on rejected scraps of food. Thus Petersen, who wintered in northern Greenland, reports that Polar foxes used to come close to the windows of his hut in order to be fed. But we need not go so far afield in search of instances. During the hard winter of 1928–1929 a peasant of Wallgau in Upper Bavaria found one morning in his byre, among the cows and the horses, a royal stag which had sought shelter there. Not until spring came, could the beast be induced to quit the warm place and tear himself away from the manger. Perhaps the domestication of animals was begun, not for utilitarian reasons, but from a sociable impulse, and originated out of such chance happenings.

WILD PROGENITORS OF DOMESTICATED ANIMALS

However this may be, the wild progenitors of many of our domesticated animals are unknown. Most investigators derive our horses from the Mongolian wild horse (Equus przhevalsky) and from the South Russian tarpan (Equus gmelini), which only recently died out. The wild asses of Nubia and Somaliland are regarded as the ancestors of our domesticated donkeys. Sheep probably derive from moufflon and argali, the wild sheep of southern Europe and of Asia. Our horned cattle may be descended from the Asiatic aurochs (Bos primigenius), but many authorities suppose them to have had a multiple origin. As regards the goat, many trace its descent from the bezoar goat, Caprahircus ægagrus. Our pigs are probably descendants of the wild swine of eastern Asia and the countries surrounding the Mediterranean. The dog is supposed to have sprung from wolf-like ancestors, but possibly the blood of other stocks of wild dogs is mingled with the lupine. The reindeer of the Lapps are believed to be the unchanged descendants of the Quaternary wild reindeer which had so wide a range, but we do not know at what date domestication was effected. Now we shall quit human history and prehistory for a time. To-morrow I shall tell you about some of the confirmatory evidence of the theory of evolution.

SIXTH EVENING

INFLUENCE OF ENVIRONMENT

NATURA NON AMAT SALTUM

B.—I am really a little disappointed. You have rushed through your account of the phases in the history of the world with the speed of an airmail, while giving only the briefest intimations concerning matters of which I should have liked fuller details. Surely no other branch of science can excel palæontology in the way of furnishing proofs of the origin of species by gradual transformation ? When I think, for instance, of the ancestral series of the pond-snails and of the developmental series which eventuated in the production of the modern horses, I find it hard to believe that anatomy and embryology can furnish equally convincing proofs. In fossils, in the " record of the rocks ", we have direct and palpable evidence, whereas in those other fields there can surely be nothing more than vague inferences ? It seems to me that, just as the monumental inscriptions left by our ancestors and the recovery of ancient memorials from excavations give us trustworthy information about their lives, telling us more perhaps than we can learn of contemporary men by actual study of them, so, too, nothing but actual examination of fossil remains can give us trustworthy information about the life and the becoming of the organic world ?

A.—Your reasoning is not quite sound. A careful study of extant living creatures can tell us much about the way in which their ancestors lived, even when data from the remote past fail us.

B.—I don't understand what you are driving at.

A.—You remember the old saw, " Natura non amat saltum " ? In plain English, " Nature does not like to jump." She pursues her course of slow and logical development by gentle gradations. This is equally true of the development of civilisation and culture. But in both domains, that of organic evolution and that of cultural development, periods of apparent arrest alternate with periods of extensive transformation. The last hundred years, above all, have been characterised by a tumultuous advance in science and technique. But, even so, these technical advances did not come with a jump ; the new is linked with the old by transitional phases, and long retains the traces of the old. The earliest kerosene lamps show their origin out of the

THE NEW BEARS WITHIN IT TRACES OF THE PAST

colza-oil lamps of an earlier phase of illumination. The early gas lamps were shaped like the kerosene lamps they replaced ; the first electric lamps, in their turn, resembled gas lamps in form. We see the same thing in thousands of cases. The first motor-cars were like a horse-drawn carriage propelled by an internal-combustion engine; the first railway carriages were built like a post-chaise. Thus almost every innovation has something about it which gives a clue to its evolution. Doubtless palæontology supplies the most conspicuous proofs of organic evolution; but comparative anatomy, embryology, and (an important new science) bio-chemistry, speak a no less convincing language. You need merely keep your eyes open

What the Zoo tells us

when you visit the Zoological Gardens, to learn from contemplation of the animals in the enclosures and basins a good deal about their genealogy.

B.—I fear, then, I must confess, to my shame, that I have never been to the Zoo with my eyes open. I liked watching the animals, but I did not learn what you say I might have learned.

A.—Go again, not for mere diversion, but to study the peculiarities of animal structure. I will give you a few examples of how to profit by the occasion.

B.—I am all attention.

Function and Structure

A.—To understand an animal's structure, you must always bear its mode of life in mind. If you do this, you will soon recognise a law which is valid for all living organisms.

B.—What is the law of which you speak?

A.—I want you to find that out for yourself. Consider, for instance, a penguin, a swallow, and an ostrich. How different the creatures are. The penguin has a plump, torpedo-shaped body, short but powerful web-feet adapted for swimming, and its wings have been transformed into fins; the swallow is "stream-lined", with slender, feeble legs, and widespread wings; the ostrich has a large and powerful body, mounted as it were on stilts, while its wings are so little developed that it cannot fly. How do you account for these marked differences between three specimens of the avian phylum?

B.—They are related with their several modes of life.

Adaptation to Environment

A.—Right. The penguin is built for marine life; the swallow, for perpetual circling in the air; and the ostrich, which lives on steppes and in the desert, is mainly dependent upon the strength and speed of its legs for seeking food and escaping its pursuers.

B.—You mean that all living creatures are adapted to the conditions of existence under which they live?

A.—I knew you would hit upon the law yourself! Really it is a commonplace, for no creature could exist unless thus adapted. For

Intestinal Worms

example, if the intestinal worms which infest man and the lower animals were unable to excrete substances that render the digestive juices of their hosts harmless, they could not live where they do, and would be digested like any other piece of meat which finds its way into the alimentary canal. Still, though adaptation is a commonplace, we can learn a great deal from it.

B.—How did adaptation arise?

A.—Hullo, my friend, now it is you who wish to travel with the velocity of an airplane! We haven't got so far as that. The difficult question of the origin of suitability to surroundings on the part of organisms will come up for discussion later. Our present concern is with the proofs of the theory of evolution. A comparative study of the locomotive organs of vertebrata will help us in our quest. You can note instances whenever you go for a walk. In men and monkeys, the fore-limbs are mainly prehensile organs; in horses and bovines, they end in hoofs; in bats, they have been transformed into wings; and in moles, into entrenching tools. Fishes have fins which serve them as oars; and the same function is fulfilled by the fore-limbs of penguins, whales, and seals. Think, also, of the magnificent pinions of eagles, albatrosses, seagulls, storks, and the other feathered monarchs of the air, and compare with them such birds as ostriches, which have completely lost the power of flight. In the kiwi, that strange New Zealand bird, there is no outward sign of wings; and the extinct dinornis was likewise wingless. You will note a kindred atrophy of both anterior and posterior extremities in snakes, and in the blind-worm or slow-worm (which is classed, not with the serpents, but with the lizards). Whereas the body of most of the lizards is upborne by agile limbs each ending in five clawed toes, in the gecko, another of the lacertidæ, the digits are modified into sucker-like appliances, which enable the animals to run up walls and across ceilings. In the chameleons, yet another order of lizards, the hands and the feet have become adapted for grasping, the fingers and toes being fused in bundles of two or three, which are opposable. I have merely chosen a few examples haphazard. So extensively are the fore-limbs of these various creatures modified to fit them to different uses in various modes of life, that on cursory examination you would find it difficult to believe them all derived from the same ground-plan.

Identity of General Plan notwithstanding Diversity of Structure

B.—I quite agree.

The Primordial Fin

A.—Nevertheless, all these variously modified limbs are derivable from a primordial fin, technically known as the archepterygium, which persists almost unchanged in certain primitive fishes. The skeletal basis of the human hand and that of a bird's wing are practically identical.

B.—That is extraordinary. I wish you would tell me more about the structure of these extremities.

ORIGIN OF FINS IN FISHES

A.—All right. We will, in this respect, hold a review of the chief types of vertebrates. If I sometimes digress from my main theme, it will only be done in order to facilitate the understanding of matters that will come up for consideration later. The lowest class of vertebrates consists of the fishes. Since they live in the water, their extremities have developed as oars, known as fins, which are paired and unpaired or median. From the evolutionary outlook, the unpaired fins arise out of a single fold of skin which begins immediately behind the head, as a dorsal crest, and extends back to the anus. In most fishes, during early youth, this simple crest becomes modified into three unpaired fins, the dorsal, the caudal, and the anal. The paired fins also develop,

PAIRED AND UNPAIRED FINS

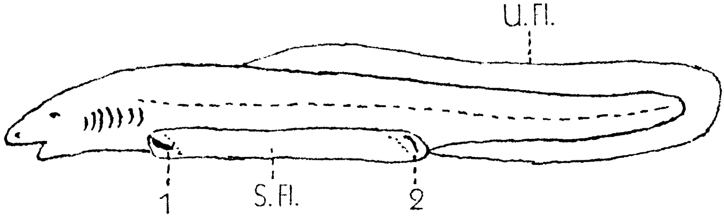

FIG. 16.—EVOLUTION OF FINS.

U.Fl, median fin-crest ; S.Fl, lateral fin-crest ; 1, rudiment of pectoral fin ; 2, rudiment of ventral fin.

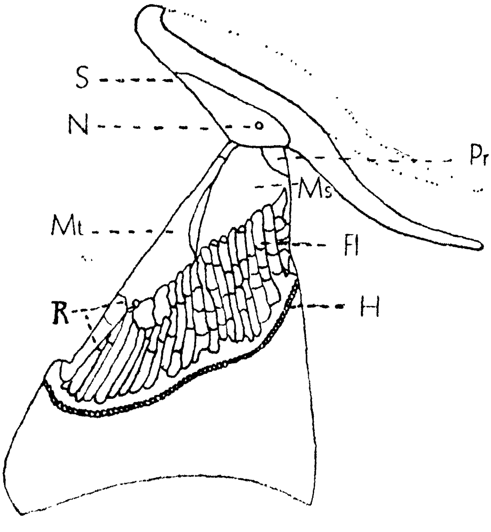

FIG. 17.—SHOULDER-GIRDLE AND PECTORAL FIN OF HEPTANCHUS.

S, shoulder-girdle ; N, nerve-foramen ; Pr, propterygium ; Ms, mesopterygium; Mt, metapterygium ; R, fin-rays lying in the axis of the metapterygium ; Fl, cartilaginous fin-rays ; H, horny threads in cross-section.

on each side, out of a primarily simple lateral fold of skin, which subsequently divides into the pectoral and ventral fins. At an early stage, skeletal elements appear in these cutaneous folds, to give them the necessary attachment to the trunk and enable them to be used as organs of propulsion. Phylogenetically, the median fins are the

LANCELET AND LAMPREY

earlier acquirements, appearing already in the very lowest types of fishes, the amphioxus or lancelet and the cyclostomata, which have not yet developed paired fins.

B.—I should understand much better if I had ever seen the creatures of which you speak.

A.—Probably you have never seen an amphioxus, but I think you must be familiar with the appearance of one of the cyclostomata.

B.—Cyclostomata, " round-mouthed fishes " ? I don't think so.

A.—I am sure you have often eaten pickled lampreys ! The lamprey, Lampetra fluviatilis, is one of the best-known of the cyclostomata. Since fins are specially adapted for the locomotion of a creature that lives in water, the median or unpaired fins vanish when terrestrial life has begun. True, in the amphibia, during the embryonic stage, a median crest like that out of which the unpaired fins of fishes develop is formed, but it contains no skeletal elements, and it usually disappears as the creature grows up. On the other hand, the paired extremities of the higher vertebrates undergo diversified changes to fit them to the more varied functions requisite for the conquest of the land and the air. This makes them peculiarly interesting from the outlook of the comparative anatomist. As already said, in every

THE FIVE-FINGERED AND FIVE-TOED EXTREMITY

one of the higher vertebrates, much though their limbs may differ in appearance and use, the structure of the extremities is derivable from that of the primordial paired fins. The accompanying diagram shows you the arrangement of the primitively cartilaginous skeletal elements of the extremities (Fig. 17). Using the human arm for purposes of comparison, the mobile rod projecting from the shoulder-girdle corresponds to the humerus, and the bifurcate cartilages attached to the peripheral extremity of this rod represent the ulna and the radius. From the cartilaginous plate situated at the distal end of these, develop the metacarpal bones ; and, phylogenetically, the fingers arise out of the skeletal elements which radiate from the farther end of this plate. The limbs of all the higher vertebrates still arise in the same manner during embryonic life. The various transformations of the five-fingered and five-toed extremities, such as occur in all vertebrates from the amphibia upward, are brought about by the overgrowth or undergrowth of particular skeletal elements, in conjunction with suppression or fusion of some of the fingers or toes. While the extremities were still used only as oars, their skeletal equipment needed to be nothing more than simple cartilaginous or bony plates. Transition to life on land entailed new tasks. Now the arms and the legs had to lift the body and to propel it in an entirely new way. This necessitated the breaking-up of the extremities into segments which could move one upon the other. Joints had to be formed.

WINGS OF BIRDS

B.—Still, with the best will in the world, I cannot detect any trace of five digits in the wing of a duck or a barn-door fowl.

A.—I fully understand your difficulty. But let me remind you of the structure of the wing in the primordial bird, archæopteryx. Here we can plainly distinguish at least three separately mobile fingers. To understand the structure of an organ (I reiterate), you must always bear its functions in mind. Then it will become plain to you how various functions have brought about deviations from the primary scheme. This applies to the bird's wing. To adapt it to its special tasks, whether for flight, as in the pigeon, or for diving, as in the penguin, extensive fusions of the various skeletal elements occur. But if you examine the embryo of a penguin in an early phase of embryological development, you will find in the wing which is later to be retransformed into a fin three distinct fingers and a rudimentary fourth one. Here you have proof that this bird, like others, has developed from a polydactylous ancestry.

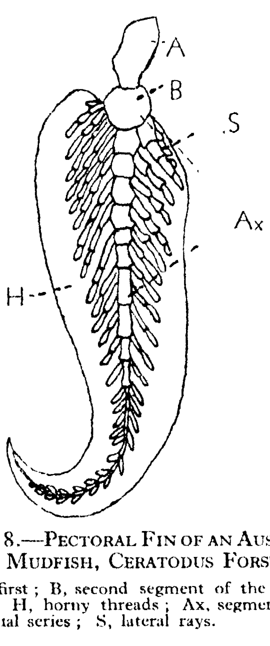

FIG. 18.—PECTORAL FIN OF AN AUSTRALIAN MUDFISH, CERATODUS FORSTERI.

A, first; B, second segment of the main stem; H, horny threads; Ax, segments of the axial series; S, lateral rays.

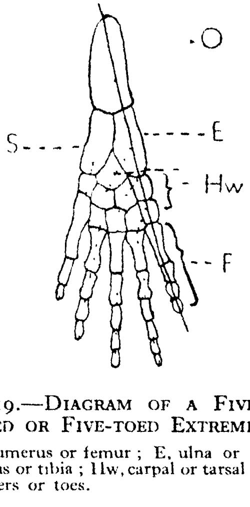

FIG. 19.—DIAGRAM OF A FIVE-FINGERED OR FIVE-TOED EXTREMITY.

O, humerus or femur; E, ulna or fibula; S, radius or tibia; Hw, carpal or tarsal bones; F, fingers or toes.

B.—All the same, I can't get it into my head that the human hand or a bird's wing can have evolved out of a fish's pectoral fin. When we contemplate a fish in its natural element, when we see how perfectly the fins are adapted to a subaqueous life, it seems almost incredible that so highly specialised a tool can ever have become applied to other uses than those of swimming.

Gurnards

A.—Visits to an aquarium must have shown you that in many fishes, even, the fins have been adapted to other uses than swimming. Don't you remember having noticed a remarkable fish which sometimes crawls on spidery legs over the floor of the tank?

B.—No doubt you are speaking of the gurnard, but this creature has, as you say, legs as well as fins.

A.—They are not legs in the strict sense of the term. The so-called legs are cirri, three anterior rays of the pectoral fin, freed from its membrane, and utilisable for ambulatory purposes. The sapphirine gurnard, Trigla hirundo, is so interesting a creature that we will pause a while to consider it. We are at once impressed by its stout body and its plump, square head, this latter being protected by a rough cuirass. Another strange characteristic is the grunting noise it makes when taken out of the water—hence its name (from the French *grognard*, the grunter or grumbler).

B.—Never before have I heard of a talking fish.

A.—That phrase is an exaggeration. The " grumble " of the gurnard, which resembles the grating noise made by unoiled hinges, is emitted by gentle friction of the gill-covers against the gill-containers. You can hear it, not only when these fish are netted, but also when they rise to the surface of the water in play. Now about the cirri. I have already explained their formation. When the fish is swimming, these free rays of the pectoral fin are closely applied to the body, but they can be used as " legs " with which to walk on the sea-bottom. Even more interesting is the modification of the fins which has taken place in certain fishes closely akin to the gurnards. I cannot doubt that you must have seen flying fish in the course of some of your many voyages.

Flying Fish

B.—Yes, when I was in the Mediterranean a number of them fell on the deck of our steamer.

A.—I expect they were specimens of Cephalacanthus or Dactyloperus volitans, the flying gurnard, which is widely diffused in the Mediterranean. It is not unlike an ordinary gurnard, though a good deal smaller in body, and equipped with comparatively much larger pectoral fins. These are fan-shaped, and the rays that support the " wing-membrane " are about a foot long. Especially in fine weather, Cephalacanthi volitantes can often be seen emerging from the water to fly down wind for as much as a hundred yards. In truth the term " flight " is a misnomer, the manœuvre being what aviators call " vol-planing ". The so-called flying fish is a " glider ". We know more than fifty species of fishes which have acquired this habit. Besides the flying gurnard, the greater flying fish, Exocoetus exiliens, and the common flying fish, Exocoetus volitans, are the best known.

B.—What biological advantage can a fish derive from this practice of leaping into the air and gliding for a long distance down wind?

A.—As a rule, flying fish leave the water to escape the attack of an enemy which would otherwise devour them. But I am unable to tell you how the gigantic development of their pectoral fins has been brought about. It is easier to explain the atrophy of the paired fins which has occurred in eels, muraenæ, and similar elongated fishes. With the lengthening of body and tail, these creatures come to be propelled through the water by serpentine movements, so that the activity of their fins passes into abeyance. In extreme cases, the fins become superfluous, and therefore atrophy.

Atrophy of the Fins

Use and Disuse

B.—Did not Lamarck try to account for the origin of species through the strengthening effect of use and the weakening effect of disuse ?

A.—Yes, he tried ; but the matter is less simple than Lamarck and his disciples supposed. The problem of the inheritance or non-inheritance of acquired characters (a problem which will subsequently come up for discussion) plays a decisive part here.

B.—I suppose the atrophy of the limbs in serpents and blind-worms is brought about in a similar way to the atrophy of the paired fins in eels, etc.?

Lengthening of the Axis of the Body

A.—Certainly. Frogs, which are short-bodied and tailless, have powerful limbs, well adapted for jumping, swimming, and climbing. In the elongated salamanders, the limbs have already become comparatively small ; in the still more long-drawn-out " Congo snake " or amphiuma, and in the snake-like blind-worm, the extremities have degenerated into inconspicuous rudiments or have completely disappeared. We see a kindred process at work in the reptiles. Tortoises, lizards, and crocodiles have powerful and well-developed fore and hind limbs ; but in the elongated blind-worm it has become impossible to detect any outward sign of the extremities, though rudiments of these still exist under the skin. In snakes the process has gone farther still, the shoulder-girdle and the pelvic-girdle, respectively connecting the fore-limbs and the hind-limbs to the vertebral column, having vanished, except in the case of some of the giant snakes, in which rudiments of the pelvic-girdle and of the hind-limbs have persisted. These rudiments, however, play no part in locomotion, being preserved merely for use as clasping organs in the act of copulation. Herein we have an instructive example of the way in which organs that have lost their pristine function through the adoption of a new mode of life can be applied to new uses. Furthermore in snakes the loss of the limbs is not merely compensated by the extreme elongation of the body, but the excessively lengthened and freely mobile ribs are pressed into the service of locomotion.

Change of Function

B.—I don't think these phenomena can be paralleled among birds and mammals ?

Long Tails and Weak Limbs

A.—Not in such extreme degrees. But if, next time you go to the Zoo, you spend an hour in the monkey-house, you will notice that monkeys with prehensile tails have comparatively weaker limbs than the short-tailed or tailless baboons and anthropoid apes.

Transition to Life on Land

B.—I still find it hard to understand how the limbs of land-dwelling vertebrates can have developed out of the fins of fishes. What can have induced a fish suddenly to quit the water (to which its whole structure was adapted), and try to live on land ? Gills are not fitted to withdraw oxygen from the atmosphere, and soon become dry there. A herring, for instance, dies almost immediately after being netted and brought aboard ship. Surely, then, all rash attempts to exchange a sub-aqueous for a terrestrial existence must have been punished by the adventurer's speedy death ?

A.—Of course the transition from life in the water to life on land was not effected suddenly. Nor do we know the motives which induced water-dwellers to become land-dwellers. Probably the urgent need for new hunting-grounds was at work. Evidently, moreover, there must have been preliminary changes in bodily structure to enable the animals concerned to endure terrestrial life for brief periods at the outset. Perhaps you have heard that of nights an eel will leave the river and wriggle for miles across damp meadows ? This is rendered possible by a tight closure of the gill-flaps, so that enough water is retained in the gill-cavities to keep the gills moist.

Periophthalmus Koelreuteri (The Mud-Hopper)

The walking fish or jumping fish, Periophthalmus koelreuteri (generally called the mud-hopper), one of the commonest fishes of the Indian Ocean, which abounds on the East Coast of Africa, a lively little creature about six inches long and able to adapt its colour to its environment after the manner of a chameleon, has prominent retractile eyes, as useful for vision in the air as when submerged. Inhabiting tidal waters, large numbers of them are left stranded when the sea ebbs, and then advance landward by jumps. Their pectoral fins are shaped somewhat like legs, and can even, it is said, be used to climb trees in the hunt for the small crustaceans on which mud-hoppers feed. Yet more remarkable than the transformation of their pectoral fins into jumping, walking, and climbing organs, is the adaptation of their respiratory organs to a temporary sojourn on land. This is a matter to which we shall return.

Swimming-Bladder and Lung

B.—You referred some time ago to the strange mudfishes, which can likewise live out of water for a long time.

A.—In the mudfishes, and especially in the Australian barramunda

(Neoceratodus forsteri), adaptation to terrestrial life is achieved in a very different way. The swimming-bladder or air-bladder has been turned to account for respiratory purposes in addition to the gills, being transformed into an elementary lung by the enlargement of its richly vascular inner surface. This organ enables mudfishes or "lungfishes" to absorb oxygen directly from atmospheric air. In the barramunda, moreover, both pairs of fins have developed to become something like limbs, but they are not strong enough to sustain the plump body, which sometimes attains a length of six feet. These creatures are not yet fully adapted for terrestrial life, but the drying-up of the waters in which they dwell forces them to become occasional air-breathers. As I said before, preliminary new adaptations must be made before an animal can enter upon a new mode of life. The adaptation of an organ to its function is never so highly specialised as to permit of the performance of only one task. Let us take the swimming-bladder as an example. This begins as a diverticulum from the œsophageal wall and remains connected with the œsophagus by a tube known as the pneumatic duct. Originally the swimming-bladder or air-bladder served exclusively as a hydrostatic apparatus, its distension with air or its deflation modifying the specific gravity of a fish to suit the depth at which it wishes to swim or to the salt-content of the water. Embryologically, therefore, it has a similar origin to our lungs, which also arise as a diverticulum from the alimentary tract, but are destined for the fulfilment of a very different function. Still the hydrostatic purpose of the swimming-bladder did not stand in the way of this richly vascularised organ being also used, when the fish was out of water, for the direct absorption of oxygen from the air. It was capable of being utilised for respiratory purposes.

Natural Selection gets to Work

When the waters in which they lived dried up, those fishes that were wholly dependent upon gill-breathing perished, whereas those whose swimming-bladders were exceptionally well vascularised, so that they had a supplementary way of keeping their blood oxygenated, had a better chance of surviving periods of drought. This provided a fulcrum on which the lever of natural selection could work, in order to strengthen the new faculty. The example, crude though it be, will show you how the function of an organ can be gradually changed, and how the change of function can then determine a change of structure.

B.—I thought it was the other way about. I believed that adaptations were evoked by the conditions of life; but now you tell me that adaptations to a new sphere must already exist before an animal can emigrate!

A.—My statement is not so paradoxical as it may seem to you at first sight. What you have to grasp is that life implies adaptation. Even the most primitive organisms, such as we may suppose to have

Life implies Adaptation

originated by spontaneous generation, must obviously be capable of performing certain vital functions, and must therefore be adapted to their environment, if they are to nourish themselves and to reproduce their kind. Since, however, even in the lowest organisms (those that reproduce by simple fission), the offspring are never exactly alike—any more than two exactly similar leaves can be found on a tree that bears thousands—the differences leave scope for natural selection. Those individuals which are in certain respects better equipped, have a greater chance of surviving in the struggle for existence, and of transmitting their superior qualities to their offspring.

B.—I am still rather "at sea" about this. Perhaps I shall understand better if you give me a concrete instance.

A.—Suppose that an amœba divides. It may chance that the cell-body of one of the daughter cells consists of rather more fluid protoplasm than that of the other. This may enable it to thrust out its pseudopodia more rapidly than its sister can, and thus more quickly envelop its prey than can its more slothful partner. According to the Darwinian theory of natural selection, this faculty can be strengthened in successive generations by preferential survival and the working of heredity. After a while there will be two races of amœbæ, one consisting of lively and active specimens, the other of dull and inert ones. So long as there is an abundance of food, both races may continue to exist side by side; but when a season of scarcity comes, you can well imagine that the lethargic race will be likely to die out, whilst the more active one will continue to make good. You know the quizzical old question, "Which came first, the owl or the egg?"; and the Indian folk-fancy that the world is supported by an elephant, which stands upon a giant tortoise, which stands on another elephant, which stands on another giant tortoise, and so on and so forth. In like manner, here. A certain degree of adaptation is indispensable to life, under whatever conditions. Gradually, however, the adaptations may become more specialised,

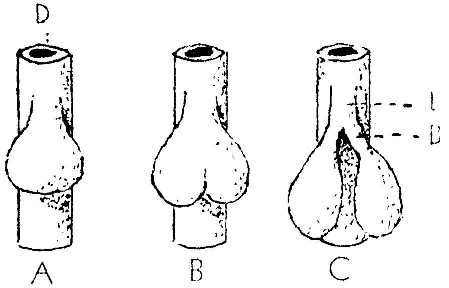

FIG. 20.—DEVELOPMENT OF THE LUNGS SHOWN DIAGRAMMATICALLY IN THREE STAGES.

D, alimentary canal; Ls, lung-sac; L, trachea. In A, the lung-sac is still median and unpaired; in B, it has begun to divide; in C, it has separated into two sacs, each connected with the trachea by a distinct bronchial tube.

until the animals concerned are enabled to exist under the most peculiar and most unfamiliar conditions.

Tree-Climbing Fishes

B.—I understand. But now I want to ask you a question which perhaps is out of season. Just before we came away, I saw in an aquarium a fish which, according to the label on the tank, bore the strange name of "the tree-climber". Are there really fishes which climb trees?

A.—I am glad you have brought up the matter. Your question is by no means unseasonable. The tree-climbing fish, Anabas scandens, is a remarkably fine example of a far-reaching adaptation to air-breathing and terrestrial life. It belongs to the group of fishes known as labyrinthibranchi, the name being derived from an expansion of the gill-cavity into the so-called labyrinthine apparatus. Over the first and second branchial arches there is a cavity containing a much-convoluted skeletal element, the labyrinth, which develops out of the first bony branchial arch. Like the swimming-bladder of mudfish, both the labyrinth and the inner side of the gill-cavity in this region are covered with a mucous membrane which is richly vascularised, containing a fine-meshed network of capillaries. There are two openings into the labyrinthine cavity, one connecting it with the fish's mouth, and the other leading to the exterior through a short tube which opens just below the gill-cover. If you watch one of these tree-climbing fishes, you will notice that it frequently rises to the surface and snaps at the air. Should you prevent this by stretching a net horizontally an inch or two below the surface of the water, you will be astonished to find that anabas can be drowned. They will perish for lack of air, just as you would perish if your head were held under water—though not so quickly as you.

Fishes that can be drowned

B.—To-day, you are telling me things that seem barely credible!

A.—That Anabas scandens can be drowned is an indubitable fact. Sub-aqueous breathing by means of the gills does not keep its blood sufficiently aerated, and it suffocates if it cannot gain access to the open air. The labyrinth is its organ for atmospheric breathing. As to the tree-climbing, the Tamil name for these fish, *paneiri*, signifies "tree-climbers"; and in a book of Indian travels dating from the ninth century A.D. we read of a fish which was able to climb palm-trees with the aid of its serrated gill-covers (opercula) and its mobile spiny fins. I will not guarantee this, but the fact is well attested. Unquestionably anabas is prone to leave the water and wander across the land. Experiments on these creatures kept in aquariums have shown that they can live out of water for as long as six days.

B.—You amaze me.

Loaches

A.—You need not go to distant parts of the world in order to make the acquaintance of fishes which practise air-breathing as a supplement to gill-breathing. There are at least two of the loaches, Cobitis tænia, the spined loach, and Cobitis fossilis, which you will find buried in the mud of many German ponds, that do this. The latter, known in the vernacular as the Schlammbeisser (mud-biter), has habits you can study for yourself by netting a few specimens with a ground-net. (These fishes are also called "groundling" because of their way of burying themselves in the mud.) From time to time they disinter themselves, swim to the surface, and breathe. But they do not breathe with the aid of a modified swimming-bladder, like the mudfishes previously considered, nor do they breathe with a gill-labyrinth like the tree-climbers of India; they swallow the supplementary air they require. When, after a while, they return to the surface, they expel a bubble of deoxygenated air from the anus. The mucous membrane of the hinder part of the mid-gut is richly vascularised for respiratory purposes, forming a sort of intestinal lung. Thanks to this adaptation, the "mud-biter" can survive considerable periods of drought. Neither the labyrinth nor the intestinal lung, however, has proved one of nature's most successful experiments. The higher vertebrata, both the permanent land-dwellers and those that have returned to an aqueous life, all breathe by means of lungs, of which the modified swimming-bladder was the first rough sketch. A permanent life on dry land imposed new and heavier tasks on the limbs. This began already with the amphibia, to become much more marked in the reptiles and in their avian and mammalian offshoots. Hence the limbs of the true land-dwellers and air-dwellers among the vertebrates show the most extraordinary multifariousness to fit them for their diversified tasks. There is not enough time for a detailed description of the various adaptations of the kind, but I know you would like me to tell you of some of the most characteristic.

INTESTINAL BREATHING

THE EXTREMITIES OF LIZARDS AND BIRDS

B.—Please.

A.—The true lizards are running animals, and have typical five-fingered and five-toed extremities. But the limbs of the various species differ enormously in accordance with their mode of life. The South American teguexin, a scaly lizard ranging up to three or four feet in length, has acquired the habit of digging long burrows among the roots of trees. Accordingly, its fore-legs are very powerful, and the "hands" end in sharp claws, which are useful excavators. Lizards that live in deserts often have spatulate toes, or else toes with lateral fringes, enabling the beasts to run over fine sand without sinking in. Of the gecko and the chameleon I have already spoken. Now set your imagination to work upon the contrast between the structure of lizards and the structure of birds, especially those that are good fliers. In these latter, lightness and elegance predominate. They look as if created for their chosen element. How has nature solved their problems for them? I do not propose to say much here about the general structure of birds. Enough to refer cursorily to the lightness of their bones, which contain numerous air-cavities ; to the air-sacs interspersed throughout the body, supplied with air from the lungs, and reducing body-weight to a minimum. My

FUNCTION MAKES STRUCTURE

main purpose now is, by a study of the limbs, to show you how " function makes structure ". The first thing that strikes us, when we compare a bird's wing with the fore-limb of a salamander or a lizard, is the marked elongation (in the former) of the skeletal elements. The whole aim seems to have been to make as long and as powerful a lever as could be, for the attachment of the pinion. The better the flier with which we are concerned, the more notable is the lengthening of the bones of the arm and the hand. In one of the most tireless of the long-distance birds, the albatross (Diomedea exulans), whose length from beak to tail is about three feet, the span of the wings is four times as great. An albatross will follow a steamer for many days. Close examination of a bird's wing will show that there has been a considerable reduction in the number of carpal and metacarpal bones and also in that of the phalanges, and that this reduction has partly been effected by the growing together of ancestrally distinct bones (Fig. 21). Thus a considerable lengthening has been achieved without any loss of firmness and strength. When we compare with the brachial skeleton of a modern bird that of archæopteryx, which must have been a very primitive flier, we see that this pioneer of aerial conquest (an offshoot from the reptilian stem) was at an extremely early stage of avian development. The " hand " of archæopteryx still had three freely mobile fingers terminating in sharp claws, which presumably enabled it to clamber amid the tree-tops and to scale cliffs, whilst it was probably content with very short flights. But evolution does not always pursue a

EVOLUTIONARY CURVES

rectilinear course in a direction once entered on. Through a change in the mode of life, what has been acquired may be surrendered.

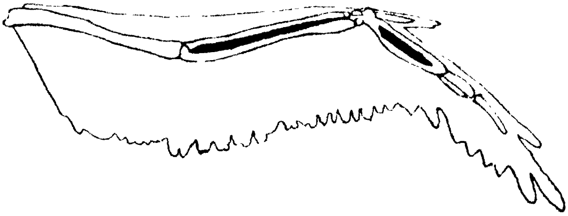

FIG. 21.—SKELETON OF AN EAGLE'S WING.

We do not know what led so many of the birds to abandon more or less completely the use of their wings, and to return to the exclusive or almost exclusive use of their legs, quitting the air for the ground. This much is clear, however, that atrophy of the wings went on concomitantly with a greater use of the legs and a consequently more vigorous development of these. There is an unbroken series of gradations (not a genealogical series) leading from the barn-door fowl to the ostrich and from the ostrich to the kiwi. The pteroclidæ (a family of gallinæ comprising sand-grouse and rock-pigeons) are still good fliers, and use their wings much more than their legs; the phasianidæ, on the other hand, use their hind-limbs quite as much as their fore-limbs, and are perhaps more at home on the ground than in the air. The tinamidæ, in turn, are loath to fly, and prefer to trust in the speed of their legs. The effect of their habits is manifest in the small size of their wings.

B.—I don't understand why the more extensive use and the stronger development of the legs should lead to atrophy of the wings. Why should not the power of flight be preserved, once it has been acquired?

The Law of Interdependence (Correlation)

A.—I have already referred to the strengthening effects of use and the weakening effects of disuse as the foundations of the Lamarckian theory of evolution. But a Darwinian explanation, based upon the theory of natural selection, can also be adduced. When an organ is little if at all used, it ceases to count in the struggle for existence. The question of correlation also comes up for consideration here. All the organs, all the tissues and cells, are mutually interdependent. Each living organism has at its disposal no more than a restricted quantity of nutritive substances, of building materials, for the development and upkeep of its various parts. If an organ is more extensively used, it requires more abundant nutriment, and what is consumed will be consumed at the expense of other organs. As Plate insists, all the parts of the animal or vegetable body are interdependent, and must have due consideration one for another. (We have a hint at this recognition in the ancient fable of the Belly and the Members!) Consequently the segmentation of the ovum, the formation of the embryonic furrow, and the normal growth of the individual organs, are matters of mutual adjustment. The food put into the Belly is not put there only for the advantage of the Belly, but for that of the Members at large. How the various demands are harmonised or to be harmonised is one of the great riddles of biology, and has not yet been fully solved.

B.—I am still a good deal puzzled about the matters of which you have just been speaking.

A.—We will go into the question more fully to-morrow. I shall give you an example which will quickly help you to understand the interdependence of the various parts of the organism.

SEVENTH EVENING

ADAPTATIONS TO LIFE IN WATER, IN AIR, AND ON LAND

An Injured Stag

B.—You said you would give me an example to illustrate the mutual interdependence of the organs.

A.—I will do so. A stag kept in a park had its left fore-hoof shattered by a rock-fall, just after shedding its antlers. The broken leg was sedulously splinted, and the fracture set well. That summer an antler with all the tines appropriate to the beast's age developed on the right side, but on the left side no antler was formed. The organism had used up as callus the material originally destined for the growth of the antler on the injured side!

B.—Did the malformation persist?

A.—No. Next year a pair of normal antlers were produced.

Ostriches

But let us return to our main topic. In ostriches, the atrophy of the wings has proceeded farther than in any of the gallinæ considered during our last conversation. All the parts of the brachial skeleton remain, but they are so small that the wings are too weak to sustain the bird's heavy body. As a recompense, the ostrich's legs are exceedingly large and powerful. The change in the mode of life has affected the whole bodily structure. The bones have for the most part lost their pneumatic equipment. In good fliers, the breastbone has a keel or carina, the crista sterni, for the attachment of the great pectoral muscles. In the ostrich, however, the carina has been suppressed as useless. The atrophy of the function of flight has gone yet farther in the kiwi, whose wings have been reduced to almost unnoticeable stumps.

B.—The theory of atrophy from disuse sounds plausible enough. But may it not be that the ancestral ostriches were likewise unable to fly? Perhaps the wingless or almost wingless birds are not descendants of archæopteryx. They may have split off earlier from the reptilian stock.

A.—Such a view has recently been advocated by Lowe, who doubts whether ostriches have sprung from an extinct type of good fliers. The wide distribution of the struthioninæ, which are found in temperate South America as well as in South Africa, suggests

Distribution of Ostriches

the great antiquity of this type. Many of the peculiarities of the ostrich's structure are also better explained by the hypothesis of a special line of development rather than by the view that these birds are the degenerate descendants of fliers. For instance, the anterior extremity of the ostrich is more closely akin in its ground-plan to the fore-limb of extinct saurians than to the wing of contemporary flying-birds. Lowe therefore believes archæopteryx, the ostriches, and the tinamidæ (which last occupy an intermediate position between the gallinacei and the ostriches) to be three independent and early branches from the reptilio-avian stem.

B.—Excuse me if I start another digression. What is the scientific explanation of the remarkable fact that the same or closely similar types are found in widely separated parts of the globe ? For instance, the ostrich of the South American pampas and the South African ostrich. It is difficult to believe that these respective birds can have been independently evolved. Surely they must have had a common ancestry ?

BRIDGES OF LAND

A.—The dispersal of identical or very similar types is regarded as a proof that, in earlier geological epochs, many countries between which the sea now rolls must have been connected by bridges of land, along which animals could spread from their place of origin into what have become detached continents. For instance, there

ATLANTIS

are various reasons for believing that in Tertiary days North America was linked with Europe by " North Atlantis " and South America with Africa by " South Atlantis ". Bounded by these four continental areas there must have been a large inland sea. On the other hand, mighty deposits from the Cretaceous and from the early Tertiary show that for long ages North and South America were severed from one another by the sea. That was why animal evolution took so different a course in what are now the northern and southern sections of a united American continent.

B.—I suppose, then, that the uniqueness of the Australian fauna depends upon the very early separation of the Australasian from the Europasian continent ?

AUSTRALIAN FAUNA

A.—Yes, Australia was cut off from the rest of the dry land at the beginning of the Cretaceous, when mammalian development had only just begun. That was why the most primitive mammals, namely the ant-eater and the duck-billed platypus (egg-laying cloacate mammals), and also the marsupials—which finds in the Eocene of Europe and America show to have had a world-wide distribution, were able, not only to maintain themselves in Australia, but to develop a very large variety of types. In America

Restriction of Marsupials

there survived only two marsupials, the opossum (didelphys) and the Æneas rat (cheironectes). For the most part they were speedily exterminated alike in the Old World and the New by the rapid development of beasts of prey. In Australia, however, marsupials blossomed almost as effectively as mammals did in other parts of the world, differentiating into the eaters and the eaten. They produced beasts of prey: the marsupial wolf (thylacinus), the marsupial bear (the ursine dasyurus or "Tasmanian devil"), the predatory opossum (another dasyurus); insectivora, such as the bandicoot or marsupial badger (perameles); a mole-like creature with powerful claws (notoryctes); the slothful wombat (phasocolomys), which resembles a rodent; and the macropodia, which remind us of ungulates, animals which progress by hopping, for their fore-limbs are atrophic, whereas their hind-limbs and tails are large and powerful.

The Kangaroo

B.—Are kangaroos ungulates?

A.—I only said they remind us of ungulates. They are true marsupials, but their four-toed hind feet have been modified into something like hoofs. That is one of the most striking outcomes of organic evolution. Animals phylogenetically distinct may, when they adopt the same mode of life, approach one another so closely in structure as to become more alike than species belonging to the same family but living under very different environmental conditions. Thus

Iguanas and Agamas

it comes to pass that the iguanas of the New World, which live in trees, are much stronger in build than the iguanas of the Old World, whose habitat is terra firma, whereas the ground-dwelling agamas are extraordinarily like the ground-dwelling iguanas. (The agamidæ and the iguanidæ are the two sub-families of a kind of saurians. "Agama" is the name used by the natives of Guiana for a creature which is found also in Egypt. "Iguana" is likewise a modification of a native—Carib—name.) The most marked anatomical distinction between these two sub-families of lizards lies in the insertion of the teeth. The agamas are acrodontic, their teeth growing (like our own) from the free margin of the jaw. The iguanas are pleurodonts, one side of the fang of the teeth being anchylosed with the inside of the socket.

Island Fauna

B.—If life under peculiar environmental conditions has so marked an effect upon the evolution of a species, then the fauna and the flora of coral islands or volcanic islands remote from the great continents must have exceptional characteristics.

A.—These islands certainly provide us with some of the most convincing proofs of the doctrine of evolution. It may, indeed, be

GEOGRAPHICAL DISTRIBUTION OF ANIMALS CONFIRMS THE THEORY OF EVOLUTION

unhesitatingly asserted that the geographical distribution of animals provides striking confirmation of the validity of the theory of descent as against the theory of special creation. Almost all remote islands

ENDEMIC SPECIES

and archipelagos have an exceptionally large number of what may be called endemic species—i.e. species found nowhere else in the world. Inasmuch as volcanic islands were, to begin with, arid and azoic, such living organisms as they now contain must have been introduced from the nearer continents, and in isolation, had ample opportunities for differentiation, and for the formation of new species.

INSECTS OF KERGUELEN LAND

To give but two examples among many, Kerguelen Land, or Desolation Island, lying far south in the Indian Ocean (49° south latitude and 70° east longitude) contains thirty-five endemic species of insects, most of which have forfeited the power of flight. An adaptation which was very useful for continental life has been lost under the changed conditions.

LOSS OF THE POWER OF FLIGHT

B.—But surely a capacity for flight must, in Kerguelen Land no less than elsewhere, have given those insects that possessed it an advantage in the struggle for existence ? The loss of it seems to conflict with the theory of the development of faculty and structure through preferential survival in the struggle for existence.

A.—Darwin considered that the atrophy of the wings in the Kerguelen Land insects afforded signal confirmation of his theory of natural selection. On this volcanic island, whose area is no more than 1480 square miles, and where terrific storms rage, flying insects were exposed to the perpetual risk of being blown out to sea, and the less efficient fliers had better chances of survival. (Much as it has been asserted that among human beings more swimmers than non-swimmers are drowned—because swimmers more often expose themselves to the risk of drowning ! But here we are dealing with an artificially acquired capacity. Strangely enough, our race has lost the instinctive faculty for swimming, which most mammals possess.) In St. Helena—another isolated volcanic island—among the 129 indigenous species of beetles, all but one, and among the 20 species of snails and slugs all without exception, are endemic. More especially do we find that there is great monotony in the flora and fauna of such islands. Terrestrial mammals are, with few exceptions, lacking, unless they have been introduced by man.

COLONISATION OF VOLCANIC ISLANDS

B.—I find it hard to picture how a region so barren as a newly formed volcanic island can ever have become colonised with animals and plants. I suppose plants must come first? But surely an almost interminable duration of time must elapse before the formation of soil on which plants can thrive?

A.—Recall our ascent of Vesuvius, in 1926. This was barely twenty years since the last great eruption, and yet upon the recent lava-fields and masses of scoriæ there was already visible a new growth of plants—exiguous, indeed, but unmistakable. Weathering occurs with remarkable speed, and a thin stratum of humus is quickly formed. At Krakatoa, an island in Sunda Strait between Java and Sumatra, a formidable volcanic eruption took place in August 1883. All the plant life and animal life of the island was destroyed. Three years later, the director of the famous botanical gardens at Buitenzorg near Batavia, visiting Krakatoa, found that eleven species of ferns and fifteen species of flowering plants had already established themselves on the devastated area. Ten years later, the species of flowering plants numbered ninety-two. Here colonisation could make rapid progress, for Krakatoa is so near Java that seeds and spores can easily be transported to the island by birds and ocean currents. Insects and larvæ are frequently borne to such islands by driftwood. The hard-shelled eggs of reptiles can also survive a long sea-voyage, whereas the soft-shelled eggs of amphibia perish. Only by some fortunate accident can mammals be transported to such places, and the "accident" usually bears the name of man. That is why we not infrequently find reptiles on volcanic islands, amphibia and terrestrial mammals hardly ever. But enough of this.

KRAKATOA

THE SHOVEL-NOSED STURGEON

B.—Not so fast. I want you to explain me something else. If the theory you have just been expounding is correct, why are certain types found in widely separated areas though lacking in the intermediate regions? For instance, the shovel-fish or shovel-head (the shovel-nosed sturgeon), of which I recently read that one species is found in the Mississippi and another in the Yangtsekiang.

SCATTERED TYPES OF ANIMAL

A.—There are many similar instances of widely scattered types. For instance, tapirs, which are indigenous to Malacca, Borneo, and Sumatra, are not found anywhere else in the world except in Central America and South America. Rhinoceroses, again, are confined to Africa, Hindustan, and Further India, and the Great Sunda Islands (Java, Sumatra, Borneo, Celebes, Banka, etc.). The alligators of the Mississippi are most closely resembled by a species peculiar to the upper reaches of the Yangtse. The restricted distribution of marsupials has already been considered. The primitive wormlike arthropod peripatus is extremely scattered, one species being found in South Africa, a second in New Zealand, and a third in Cayenne. Lemurs inhabit Asia, Madagascar, and the African continent. Strangely enough, the Asiatic and the African lemuridæ are more closely akin to one another than they are to the lemurs of Madagascar. Have I given you enough examples ?

B.—For the moment, yes. But it seems to me that the facts you have just adduced are in conflict with what I should have inferred from the doctrine of descent.

AUTOCHTHONOUS OR HETEROCHTHONOUS ?

A.—Certain difficulties indubitably arise in this connexion, even though most of the cases are fully explicable in the light of our extant knowledge of the earlier distribution of lands and seas. The fauna of any area must either have originated in situ, being then spoken of an autochthonous ; or must have immigrated from elsewhere, when it is styled heterochthonous. Migration from an original habitat to a new one is generally determined by pressure of population upon the means of subsistence and by the consequent need for finding fresh hunting-grounds. In other cases, climatic changes may drive a species from its home. Thus the strange annual migration of many species of birds is now commonly believed to have been brought about by the climatic hardships of the Ice Age.

B.—Yes, I want you to tell me about avian migration. One reads such conflicting views.

CREATIVE CENTRES

A.—By and by. For the moment we must stick to another train of thought. Palæontologists have been able, in the case of certain groups of mammals, and not mammals alone, to discover the existence of " creative centres " from which particular types have gradually been disseminated. The distribution of the majority of the aforesaid " scattered types " finds its most successful explanation in this way. Marsupials, lung-fish, tapirs, rhinoceroses, ostriches, etc., had a worldwide distribution long, long ago, but have during recent ages become extinct in intermediate areas owing to geological and climatic changes. I must impress on you once more how extensive have been the variations in lands and seas since the ocean was first formed upon our globe. The actual shape and size of the Europasian continent date only from the Post-Diluvial Ice Age. The English Channel, the Sound and the Belt, the Straits of Gibraltar, the Dardanelles, the Bosphorus, and the Ægean Sea are comparatively recent creations.

DISTRIBUTION OF THE LEMUROIDEA

B.—I suppose, then, that the presence of lemurs in Asia, Madagascar, and Africa denotes that in prehistoric times these areas of land were connected ?

A.—Yes, the distribution of the lemuroidea throughout a broad tropical zone extending from West Africa to the Philippines and the Timor Archipelago is taken as evidence that an enlarged Madagascar and the Sunda Islands once formed parts of a huge continent, spoken

LEMURIA

of by geologists as Lemuria or Gondwana Land, of which only the marginal portions remain, whilst the remainder lies beneath the waters of what is now known as the Indian Ocean.

B.—Still, that leaves unexplained why the widely separated lemuroidea of Asia and the African continent should resemble one another more closely than do the respective species of Madagascar and Africa.

A.—We may suppose that Madagascar was early detached from Africa and the rest of Lemuria, with the result that the lemuroidea confined to an island with climatic and other peculiarities took a different evolutionary turn from those living under other conditions in Asia and Africa. We are here concerned with a phenomenon akin to the prolific development of the Australian marsupials. There are no large beasts of prey among the Malagasy fauna. The biggest predatory animal in Madagascar is the fossa (Cryptoprocta ferox), allied to the civet, and of about the size of our domestic cat. Here flourishes the bristly insectivore, centetes.

Maximus

The huge wingless bird, Æpyornis maximus, has already been mentioned.

Giant Tortoises of the Galapagos Islands

There is also found in Madagascar the giant tortoise, Testudo elephantopus, which until a few decades ago was so abundant in the Galapagos Islands and the Aldabra Islands, but is now on the way to extinction even in these remote and isolated spots.

The Cheiromys or Aye-Aye

Another example of exceptionally close adaptation to a peculiar mode of life is found among the lemurs in the case of the Cheiromys madagascariensis or aye-aye. This creature has enormously elongated bony middle fingers armed with sharp claws, and teeth resembling those of a rodent. Like our hares, and unlike other lemurs, it has incisor teeth (both upper and lower) which continue to grow throughout life. With these chisel-shaped teeth it gnaws wood, and with its long middle finger extracts from their holes the grubs on which it feeds.

B.—Then the data of animal geography or distribution confirm the theory of evolution ?

Mississippi and Yangtsekiang

A.—On broad lines, yes. Still, there are difficulties, such as the occurrence of shovel-nosed sturgeon, and of kindred alligators, in rivers so widely separated as the Mississippi and the Yangtse.

B.—Is there no explanation ?

A.—Simroth and others have put one forward, but it is based upon rather shaky hypotheses.

B.—If the explanation is purely hypothetical, I suppose we need not waste our time on it ?

Value of Hypothesis

A.—You should not speak so slightingly of hypothesis, which is no less necessary to the acquisition of knowledge than is precise research. " There are great advantages in formulating a hypothetical law "—I am quoting Helmholtz from memory. " The first attempts at formulation, when adequate proofs are not yet forthcoming, can only be called hypotheses. The inferences from such hypotheses, insofar as amenable to direct observation, are then compared with the facts under conditions as diversified as possible, for as long as possible, and in as many instances as possible, until at length a sufficiency of material has been accumulated to convince us of the validity of the law, within the field subjected to examination." This applies to the theory of evolution, and I will ask you to consider from the same angle the not yet fully substantiated pendulation theory.

B.—I spoke hastily. Forgive me. You have my best attention.

PENDULATION THEORY

A.—Reibisch opines that our globe, in addition to its ordinary movement of diurnal rotation around the axis running from the North Pole to the South, is subject to a pendulum swing upon an axis which runs from the " swinging pole " of Ecuador to the " swinging pole " of Sumatra. There are two theories as to the origin of this pendulum movement. In Reibisch's view, the moon broke away from the earth (before the formation of the earth's crust) in the region which now forms the deep basin of the Sea of Japan. On the other hand, George Howard Darwin, one of Charles Darwin's sons, believes that at one time the earth had a second satellite, which during the Pre-Cambrian epoch fell back in the neighbourhood of Madagascar. Either of these causes would account for the origin of the hypothetical pendulum swing. According to Reibisch, this pendulum movement leads to a sort of periodical " side-slip " of the earth's crust upon its molten interior, with the result that the position of the earth's poles is not fixed but mutable. Except for the " swinging poles " in Ecuador and Sumatra, all parts of the earth participate in the movement. That would account for the periodical onset and subsidence of the Glacial Epochs, and for other rhythmical climatic variations. Owing to the aforesaid " side-slips ", the organisms that inhabit the areas most affected by the pendulum movement are necessarily exposed to new conditions of existence to which they must (to avoid destruction) react by constitutional changes—unless they adopt the simpler plan of moving along the parallels of latitude towards the " swinging poles ", and thus remaining under identical climatic conditions. This would account for the presence of kindred types of alligator in the Mississippi and the Yangtse. But, for the nonce, the pendulation theory lacks solid foundations. It has not yet been proved that the earth once had a second moon, or that the detachment of the extant satellite took place as recently as Reibisch supposes.

THE ICE AGE AND AVIAN MIGRATION

B.—You said a little while ago that the habit of many birds to fly south in autumn was probably induced by the vacillations of climate during the Glacial Epoch.

A.—A good many ornithologists are of this opinion. Whereas in the Tertiary a tropical or semi-tropical climate extended far to the north, so that in our part of the world there was an ample supply of nutriment for birds throughout the year, matters changed when the greater part of Europe became covered with an ice-sheet. In winter, especially, food ran short, and hunger led many species of birds to seek warmer climes at this season.

B.—That sounds reasonable. But why did they not remain in the sunny south ? What induced them when spring came round to fly back to the chilly north ?

Homing Instinct

A.—You touch the core of the problem. The reason appears to be that birds have a strongly developed homing instinct. This has been proved by the " ringing " of birds—the fixing of a dated and easily recognisable ring round one of the legs of a nestling. We know that storks, herons, wild-duck, wild-geese, wild-pigeon, snipe, swallows, song-birds, and birds of prey return every spring to their birthplace. Similar facts are observable in the case of migratory fishes. The larval eel, discovered by Kaup in the North Sea eighty years ago, and christened by him as an independent fish under the name of Leptocephalus brevirostris, is born in the depths of the Sargasso Sea. Having traversed the ocean, this transparent little creature (known in Germany as a " glass eel ") enters one of our rivers and swims up to the head waters. There it abides as long as nine years, but when sexual maturity has been attained the lure of the birthplace becomes irresistible. Now the migration is reversed. The adult eels swim downstream, and make their way back thousands of miles to the Sargasso Sea, where they celebrate their nuptials, lay their eggs, and (one must suppose) die. The facts are indisputable, but call for an explanation. Somehow, somewhen, the migratory impulse must have originated ; but when and how we do not know. We are equally in the dark as to the nature of the sense of orientation which guides migratory birds southward and home again, eels from the Sargasso Sea into European rivers and from European rivers back to the Sargasso Sea.

Ringing of Birds

Leptocephalus

B.—Still, it is plain that not all migratory birds return to their birthplaces. In North Africa I saw storks nesting in high summer.

A.—The African storks are indigenous to the Dark Continent, and do not cross with our European storks. There seems to be no doubt that the latter return northward every spring to breed.

Omnipotence of the Migratory Impulse

B.—I have often taken young starlings from the nest and brought them up in the house. They grew so tame that they would fly to me when I called them, but as soon as the wild starlings began to flock for their autumn flight, my pets became so fearfully restless that I had to set them free.

A.—That shows the omnipotence of the migratory impulse, which becomes active in the bird's body independently of temperature changes or lack of food. Why otherwise should our swifts prepare for their southward flight year after year in the early days of August? When the migratory impulse stirs, it overpowers all the other instincts. Migratory falcons in which it has become dominant will mingle with thrushes and finches without trying to kill them; and the smaller birds pay no heed to those which, at ordinary times, are their natural enemies. To-day physiologists refer the activation of the migratory impulse to changes in internal secretion. The "endocrine balance" is modified by the formation of some new "hormone" (stimulant or exciter). That is why the migratory impulse varies so much from individual to individual, becoming active or inactive earlier or later in members of the same species, so that some stop their southward journey in Italy, whilst others continue their flight to South Africa. The birds keep on the move only so long as the hormones or exciters are poured into their blood.

HORMONES THAT AROUSE THE MIGRATORY IMPULSE

B.—But if the migratory impulse awakens without any external cause, I find its periodicity hard to understand.

LAW OF PERIODICITY

A.—If you reflect upon the matter, you will remember that most vital phenomena are subject to the law of periodicity. Think of menstruation, and how the periodical flux is associated with an extensive modification in the menstruating woman's psychological condition. Besides, in us males the emotional state is subject to periodical changes. Without obvious external causes you will be depressed at one time and in merry mood at another. Those who practise careful introspection cannot fail to note that such changes are rhythmical. Doctors speak of "cyclothymia", a mild degree of those alternations of mood, those "ups and downs", which in graver forms manifest themselves as circular insanity, recurrent phases of mania and melancholia.

B.—Of course I recognise this law of periodicity. One of the most striking examples of it is the budding of the trees and bushes in spring, and the fall of the leaves in autumn, both occurring at fairly regular times independently of the temperature. But I did not know that there were such marked individual differences in the migratory impulse as manifested in members of one and the same species of birds.

DIVERSITY OF THE MIGRATORY IMPULSE

A.—The differences are not individual merely but show themselves as regards diversity in sex and in age. Thus the hen-chaffinch is seized by the migratory impulse in autumn, and flies south, whereas the cock birds of the same species stay behind as grass-widowers.

Furthermore, the impulse is not immutable, for it may undergo rapid modifications. Our blackbirds have during the last fifty years ceased to be migratory, and in the same period have been transformed from shy dwellers in the wild into importunate inhabitants of parks and gardens. The probable explanation is the increasing attention paid to forestry and the clearing away of the undergrowth. Starlings, too, are showing an inclination to abandon migratory ways, and to settle down for the whole year in their northern homes. This rapid change of habits does not square very well with the hormonal theory of the migratory impulse, for it is hard to understand how a hereditary, fixed, organic disposition can vanish within a few generations.

Sense of Direction

B.—A while back, you referred to the sense of direction in migratory birds as inexplicable. But I should have thought that the young birds merely follow their parents, which know the way because in earlier years they had done the same thing.

A.—That might account for many instances, but certainly not for all. Among herons, seagulls, and starlings, the young birds migrate first, the parents, which may be supposed to know the way, not starting till considerably later. Some migratory birds, again, migrate singly, not in flocks. The cuckoo is a signal instance. For unnumbered generations these birds have been hatched and reared in alien nests, but every autumn the cuckoos of that year depart for Africa along the route winged by their remote ancestors. The impulse to migrate by a particular path is as firmly fixed in the bird's organisation by heredity as the nidifying instinct which impels it (cuckoos and a few others excepted) to build in due season a nest closely resembling the one built by the parent birds.

Paths of Migration

B.—I thought the art of nest-building was taught the young birds by the old.

A.—That is a vulgar error. Give your hen-canary some linnet's eggs to incubate, and you will see the young linnets, when the nesting season comes round, build a linnet's nest if suitable materials are at their disposal. It is true that old birds build better nests than yearlings, for every " instinctive " action incorporates an experiential element, and is not carried out in a purely mechanical fashion. In like manner, an impulsive, inborn element is mingled in every intelligent action. As Alverdes aptly phrased it, instinct is a monition to use the organs, and this monition is perfected by experience.

Instinct and Experience

B.—If the young migratory birds are not guided by the old ones, I supposed they are simply lured southward by the increasing warmth ?

A.—What put that notion into your head ? No doubt you are thinking of the thermotaxic and phototaxic movements of insects, etc. The fact is, however, that at the season of the southward avian migrations the weather in the south is often colder and rougher than that in the north. Besides, on your assumption, one would expect the birds to make a bee-line for the south. Few of them do this. Most of them follow traditional and devious routes. The storks that build their nests in regions lying on the east bank of the Weser begin by flying south-eastward across the Balkans to Asia Minor, then they turn southward along the Suez Canal and over Egypt up the Nile, en route for the Cape. On the other hand, their kindred which spend the summer on the west bank of the Weser make their way to Africa south-westward across France and Spain. When the migrants return, they follow the same respective courses. You see that we are still much in the dark as regards avian migration. Many ascribe to birds what they term a " magnetic sense ", but this is a guess rather than a scientific explanation.

Speed of Migration

B.—I have always been astonished by the immense distance that birds traverse in these migrations. What tremendous and untiring strength a stork must need to fly uninterruptedly from northern Europe to Cape Colony.

A.—Exaggeration is still rife concerning both the distance and the speed of avian migrations. The speed of the best fliers on these occasions does not exceed sixty miles per hour. Then, there are frequent rests. The storks' daily flight is about 125 miles. Aviators have noticed, moreover, that migrating birds do not fly at great heights, seldom above twelve or thirteen hundred feet. Still, all deductions made, the distances covered are impressive. In the Far North, for instance, nests the arctic sea-swallow, Sterna macrura, which, when the breeding season is over, flies to the antarctic for its winter (there, summer) quarters. Following Lucanus, one of the greatest authorities on avian migration, we may say that this arctic sea-swallow is the " sun bird " in the strictest sense of the term. Except for the periods of migration, it spends almost all its life in the sunshine. But enough of digressions.

The " Sun Bird "

Feathers and Scales

B.—I want to ask you a question which bears closely on our theme. As far as I know, the feathers of birds have developed out of reptilian scales. It seems to me a reasonable supposition that the moulting of birds must correspond to the sloughing of the skin that occurs in serpents and lizards.

Sloughing and Moulting

A.—A sound observation. Besides, moulting and sloughing are excellent examples of the periodicity of vital phenomena.

B.—Are the hairs of mammals also derived from reptilian scales?

A.—No. Phylogenetically, hairs have a different origin from feathers. Biologists are inclined to regard them as modifications of the cutaneous sense-organs of amphibia. Still, though proceeding from a different source, there is at times a marked resemblance between hairs and feathers. In the kiwi, the loss of the power of flight has affected the plumage as well as the wings, and this bird's feathers have been transformed into fine, hairy structures.

The Penguin

B.—Even more remarkable than the atrophy of the wings from non-use seems to me the transformation of these organs into fins in the penguin.

A.—In the penguin such profound changes are by no means confined to the extremities. The legs, which are very far towards the hinder end of the body, give the bird an extremely upright position when on land, the tail, beset with short, stiff feathers, serving as a prop. When a penguin is in the water, the legs are directed backwards, and serve (like a fish's caudal fin) as a rudder. In place of the great articulated wings of an ordinary bird, the penguin has a broad, simply constructed fin, a sort of oar, covered with scale-like feathers. When we watch how cleverly the penguin dives, and how it can stay several minutes under water while hunting its prey, we find it hard to believe that the bird was not originally created for marine life. Even the plumage has been modified to this end, the feathers lying so close to the body as to leave scarcely any room for air.

Return to the Water

B.—Seems to me an unlucky adaptation. Since penguins live in the antarctic I should have thought they needed air-containing plumage as a protection against the bitter cold.

A.—A sound criticism. But nature has provided compensation by giving them a thick layer of fat beneath the skin, the panniculus adiposus.

Good and Bad Divers

B.—Since a bird's body is so light, owing to the pneumatic structure of the bones, and the numerous air-sacs interspersed among the muscles, there must have been great difficulties in the way of transition from an aerial to a marine life. When an ordinary duck wants to dive, one sees it raise its body high out of the water before plunging with a jerk, and even then it never achieves complete submersion. By continuous paddling movements with its webbed feet it can at best keep itself half under water, with its tail sticking out. What induced such creatures to return to life in an element for which they were no longer suited ?

A.—The food-hunt, doubtless. But there must have been a prolonged conflict in their primitive minds before they took to the water. In the penguin, however, the difficulties have been admirably overcome. Apart from the adaptations already mentioned, this bird's bones (except for the skull) contain no air-spaces. No doubt the changes took millions of years to effect. But even to-day you can see genuine fliers that hunt their prey under water. Think of kingfishers, seagulls, sea-swallows, and ospreys. True, none of these are first-class divers. They can only get under water (and that not very deep) by plunging from a height, and the specific gravity of their bodies is so low that the pressure of the water soon forces them back to the surface.

B.—Why does not a bird that dives become altogether unfitted for flight? When my canary has been taking its bath, it cannot fly until its feathers have dried.

A.—An oily secretion derived from the rump-gland prevents these birds from getting wet. The orifice of the gland is between the quills of the tail-feathers, and you must often have seen a duck burying its bill in this region and then sedulously dressing the rest of its plumage with the oil. That is why " water runs off a duck's back ".

THE PENGUIN'S FIN-FLAPPER

B.—Are the penguin's wing-bones as much atrophied as those of the ostrich?

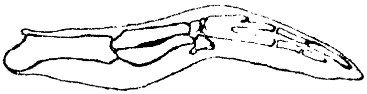

FIG. 22.—SKELETON OF A PENGUIN'S WING.

A.—No. The penguin's " fin " contains the same skeletal elements as an eagle's wing: an arm-bone; two fore-arm-bones; two carpal bones; and three metacarpal bones and phalanges—mainly anchylosed. But whereas in the eagle everything aims at the elongation of the wing, in the penguin the bones are short and flattened.

BETWIXT AIR AND WATER

B.—Sorry to pester you with questions, but one leads to another. Are there transitional forms between good fliers and penguins, to bridge the gap?

A.—Yes, though we do not know of a genealogical series, like that of the ancestral horses. There is Uria troile, the " foolish guillemot ", which nests in Heligoland. Its wings are comparatively much shorter than those of most fliers, and the wing-bones are shortened and compacted. They can still fly short distances, but their ordinary method of terrestrial locomotion is by running, the wings being then used only to keep the bird's balance. They come rarely to land except in the breeding season, spending the rest of the year on the high seas. They are skilled swimmers and divers, able to stay several minutes under water, where they use their wings and feet skilfully as oars and rudder. A further stage on the way towards the development of the penguin type was the great auk,

THE GUILLEMOT

Alca impennis, which formerly abounded in Spitzbergen, but has been extinct since 1844. In this bird, feathers still persisted in the fin-like wings, but the wings were no longer able to sustain the heavy body in the air, being useful only as oars on and beneath the surface of the water. The most convincing proof that "function makes structure" is supplied by the organs of animals belonging to widely separated families but leading a similar sort of life.

WHALES AND DOLPHINS

Even to-day the half-educated usually regard whales and dolphins as fishes. The error is comprehensible when we note the spindle shape of these creatures, their hairlessness, their powerful tails which have been converted into a bipartite caudal fin (flukes), the development of a median dorsal fin and of paired pectoral fins, and the want of a visible neck.

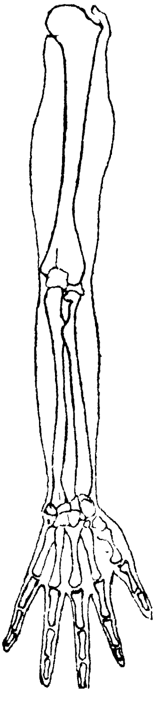

FIG. 23.—SKELETON OF A HUMAN ARM, FORE-ARM, AND HAND.

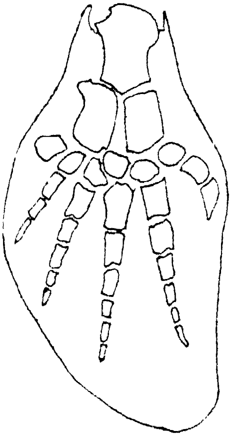

FIG. 24.—SKELETON OF A WHALE'S PECTORAL FIN.

B.—Why are whales and dolphins classed as mammals though they so closely resemble fishes?

A.—First of all, because they bring living young into the world, and suckle their offspring from mammary glands; secondly, because they are warm-blooded, and breathe by means of lungs instead of gills. The marked contrast between many of their bodily organs and those of their land-dwelling mammalian congeners is the outcome of adaptation to a marine life. All the other mammals that we know have two pairs of limbs; but whales and dolphins have only one pair of fins, the pectorals. They have no outward and visible sign of posterior extremities. Yet there can be no doubt

ANCESTORS OF WHALES

that the whales have all developed by slow gradations out of terrestrial mammals equipped with two pairs of limbs. Quite unwarrantable is the supposition of certain palæontologists that whales and dolphins have sprung directly from the titanic marine saurians of the Jurassic; their forefathers were probably primeval ungulates. A whale's pectoral fin contains the same skeletal elements as the human arm or the lion's fore-limb. But, for the construction of a powerful oar, the bones have been shortened and flattened; and instead of articulating like those of a terrestrial mammal they are strongly bound together by ligaments amid which the joint-cavity has been suppressed.

B.—What has happened to the posterior extremities?

DEGENERATION OF LIMBS

A.—Owing to the marked elongation of the body and the development of a muscular caudal fin, they no longer had anything to do, and in most species they have atrophied without leaving a trace.

B.—How is it known, then, that their ancestors had legs?

A.—There are exceptions to the completeness of the disappearance. In the Greenland-whale or right whale (Balaena mysticetus), and some of the kindred forms, there remain, deep hidden within the body and unconnected with the vertebral column, the inconspicuous but unmistakable vestiges of short thigh and leg bones.

B.—Such modifications in the structure of an organ due to changing habits seem to me one of the greatest wonders of nature.

THE MOLE AND MOLE-CRICKET

A.—Even more remarkable is it to find that in classes so widely divergent as insects and mammals, organs whose structural basis is entirely different have become outwardly similar when devoted to similar uses.

B.—Give me an instance, please.

A.—I think you must be equally familiar with moles and with mole-crickets (Gryllotalpa vulgaris). An insect's front-legs always consist of the same segmental parts, such as you see typically developed in the carabidæ (ground-beetles or garden-beetles). In the mole-cricket, however, these parts have been modified to fit them to the animal's burrowing life; have been shortened, widened, and strengthened. The fore-feet of the mole-cricket (which in most insects are jointed) have fused into a plate, which makes them resemble little spades. A precisely similar change has occurred in the fore-limbs of moles.

SPOUTING OF WHALES

B.—When I made a voyage to the Far North we sighted a school of whales, and I saw the animals from time to time spouting thick streams of water high into the air. The captain explained to me that whales did this in order to rid themselves of water they had taken into the mouth when swallowing their food.

A.—That is another vulgar error, and one which dies hard. The spouting of whales is one of their important adaptations to marine life. In whales, the nostrils are situated very far back, and can be closed by valve-like folds of membrane when the animal dives or "sounds". They also have a sphincter muscle surrounding the entrance to the larynx, whose function it is to hinder the ingress of water into the air-passages. In the respiratory organs there have been numerous valuable readjustments. A whale's lungs are extraordinarily elastic, and the lungs, which are unsegmented, extend very far tailwards, so that they can take on an accessory hydrostatic function like that of a fish's swimming-bladder. Having a greatly enlarged thoracic cavity, whales can inspire a huge volume of air, the normal interval between breaths being three or four minutes. When danger threatens, and a whale sounds, it can stay under water for as long as an hour. All the better, for otherwise ere this whalesmen would probably have made an end of the game they hunt.

UTILISATION OF LUNGS AS SWIMMING-BLADDERS

WAR OF EXTERMINATION AGAINST WHALES

B.—Unless the governments take vigorous joint action, the extinction of whales cannot be long delayed. To an increasing degree, a whaler has become a floating factory on which the blubber of the catch is boiled down forthwith, and the rate of slaughter has been greatly intensified. In 1919–1920 the total catch was 11,369; by 1928–1929 the number had risen to 27,566, yielding 1,867,848 barrels of oil.

A.—I did not know that matters were already so bad as this. But let us keep to our subject. I said that in case of need a whale could stay under water for as long as an hour. When, after so prolonged a dive, it rises to the surface, the deoxygenated air is expelled from the lungs with such violence that the water lying above the nostrils spouts upward. From this, and from the condensation of the aqueous vapour in the long-retained air, arose the fable of the whale's spouting water from its nostrils like an elephant. The look-out man's cry "'Thar' she blows" is more accordant with the facts than it is to talk of a whale's spouting. There are other ingenious provisions upon which a whale's capacity for lengthy dives depends. In many parts of the body the arteries break up into thick bundles of anastomosing arterioles, called retia mirabilia, which then reunite into an arterial trunk before subdividing in the ordinary way into capillaries. Thus a whale is enabled to retain an enormous quantity of arterial blood in its vascular system, providing for aeration of the tissues when the animal remains a long time under water. Again, the perfect smoothness of the hairless body, in conjunction with the whale's torpedo shape, reduces the friction of the water to a minimum.

RETIA MIRABILIA

B.—This hairlessness of which you speak may have been an ancestral character.

Phylogeny of Whales

A.—Embryological study forbids any such hypothesis. At any rate, in many whale fœtuses, hairs sprout on the lips and from the nostrils. These are vestiges of erectile sensory hairs like the " whiskers " of a cat, a rat, and many other mammals of nocturnal habit. When the hairy coat disappears, such sensory hairs, which are early formed, are apt to persist.

B.—Whales, like penguins, have a thick layer of fat immediately beneath the skin—the blubber from which whale-oil is extracted.

A.—Yes ; this panniculus adiposus serves primarily as a safeguard against loss of heat ; it also considerably reduces the animal's specific gravity ; and, finally, being elastic, it protects the internal organs from the great changes of pressure that occur during deep dives. The specific gravity is further reduced by the markedly spongy structure of a whale's bones.

B.—I find it amazing that such sensitive organs as the eyes should not be injured when a whale sounds.

A.—This also is prevented by a cunning adaptation. In whales, the sclerotic, the tough fibrous coat which forms " the white of the eye ", has been much thickened ; and the optic nerve is surrounded by an elastic tube of retia mirabilia. Further protection is afforded by the powerful development of the intra-orbital muscles. It is strange, on the other hand, that the eyelids cannot be closed. They have become immobile. Enough of whales for the present. I shall speak of the peculiarities of their teeth in another connexion.

Other Land Animals returning to the Sea

B.—Are seals transitional forms between terrestrial mammals and whales ?

A.—Once more, not in the genealogical sense. But just as the guillemots are links between flying birds and penguins, so the pinnipedia (seals and walrusses), supposed to have sprung from bear-like ancestors, are intermediate between terrestrial mammals and those which have completely resumed a marine life. They still have four powerful pinniform (fin-like) extremities ; their pectoral fins or flappers not only contain all the bones proper to the mammalian arm, but permit of the recognition of five clawed fingers webbed together by swimming membranes. The hind pair of flappers are directed backwards, and function as a rudder. When on land, the seals effect locomotion by wriggling movements of the body, the

Sirenia

chief use of the limbs being as supports when going uphill. The sea-cows (dugongs and manatees) and the sea-elephants were, in earnest, described by Blainville—Cuvier's successor as professor of comparative anatomy at the Collège de France—as elephants which had gone back to live in the sea. To-day these vegetable-feeding mammals, which are much more closely adapted than the seals to marine life, are believed to have been derived from ancestors resembling tapirs. Their habitat is in shallow waters or estuaries, where they crop the seaweed, and they therefore do not need to be such excellent swimmers as the dolphins, whales, and seals, which are carnivorous. In the extant sirenia nothing remains of the hind-limbs but vestiges of the pelvic girdle.

B.—In what parts of the world are these strange creatures found?

A.—The three species of dugongs, animals with breasts very like a woman's, prototypes of the fabled mermaids, are distributed on the shores of the Red Sea and on those of the Indian Ocean from Madagascar to Australia. Another genus, that of the trichechidæ, to which the American lamantin (Trichechus manatus) belongs, is found in the rivers of the West Coast of Africa, in those of Brazil, in the Caribbean Sea, and on the Atlantic coast of America from Brazil to Florida. A third family, specimens of which (ranging up to more than twenty-five feet in length) are among the largest of the sirenia, that of the sea-cows Hydrodamalis gigas, used to inhabit the Behring Sea, great herds having been seen by the second expedition to this region in the year 1741. Since then, however, they have been ruthlessly exterminated. Even more interesting than

Conquest of the Air by Mammals

the transformations which occurred in the bodies of those mammals which returned to the original home of all life, the sea, are the changes whereby certain mammals have been able to effect the conquest of the air. The fur of mammals is not, like the plumage of birds, adaptable to the purposes of flight, but nature, fertile in expedients, has been able to turn the skin to account in this direction.

B.—How ?

An Unsuccessful Experiment

A.—One of the most persistent attempts has been to spread a membrane between the fore-limb and the hind-limb on each side. But this lacked the mobility of a wing, producing merely a parachute-like structure, such as is possessed by the flying squirrels.

Flying Squirrels

B.—What are flying squirrels ?

A.—I think you ought to know. Though not fellow-countrymen, they are near neighbours. The flying squirrel is a rodent which, apart from the membrane that transforms it into a glider, closely resembles an ordinary squirrel. The European flying squirrel, Sciuropterus russicus, is distributed from what used to be the Baltic provinces of Russia to the Lena. The animal is a tree-dweller. When it wants to glide, it separates the arms widely from the legs so as to stretch the membrane by which, on each side, they are connected, and vol-planes as far as thirty feet to a somewhat lower branch of an adjoining tree. During the glide, the bushy tail serves as a rudder. Better developed is this " parachute " in the insectivorous

" flying lemur ", Galeopithecus volans, an inhabitant of Sumatra, Borneo, and the Philippines. In this creature which is of about the size of a cat, the " flying " membrane does not only stretch from arm to leg but stretches forward to the neck and backward to the tail. With its aid, launching themselves from a height of fifty feet, flying lemurs can vol-plane to a distance of more than two hundred feet from their starting-point. Now let us turn to the flying dragon

AN EXTANT DRAGON

or flying lizard (Draco volans), a reptile found in the Sunda Islands.

B.—I thought that dragons were mythical monsters.

A.—Yes, in the mythological sense of the term. There have never been huge flying reptiles contemporary with man—to say nothing of fire-breathing creatures of the sort ! The nearest approach to a dragon was the pterodactyl of Mesosoic times, extinct ages before man appeared upon the world's stage. The " dragon " of which I speak is a lovely little polychrome lizard about eight inches long which leads a retired life on the upper branches of tropical forest-trees and is dangerous only to insects. Like the flying squirrel it has a pair of semi-circular membranous parachutes, stretched however not between the extremities but upon a framework provided by the anterior five or six floating ribs, which are laterally extensible. The " dragon " lies crouched upon a branch, the movement of its eyes being the only sign of life, and inconspicuous notwithstanding its bright colouring amid the play of light and shade of the tree-tops. But when an insect flies within range, the little reptile is roused into activity. Suddenly stretching its parachutes, it thrusts itself into the void with a vigorous push of the hind-limbs, planes down upon its booty, and sails on to a lower branch, where it once more becomes inactive. The problem of gliding has been solved

THE FLYING FROG

in a somewhat similar way in the Malayan flying frog, Rhacophorus reinwardti. Here the fingers and toes, greatly elongated, serve as stretchers for the parachutes. Although there is no genetic relationship between these rhacophori and the bats, rhacophorus indicates the way in which the problem of flight has been solved in flying mammals and was also solved long ago in the flying saurians. Mammals, too, having no feathers at their disposal, have achieved the

BATS AND FLYING FOXES

conquest of the air by spreading membranous wings. These wings could only be rendered serviceable through a marked deformation of the brachial skeleton. It did not suffice to stretch the bones into long levers, but an expansible framework upon which the fold of skin could be tensed had to be supplied. For this purpose, the phalanges of the fingers were enormously lengthened. In bats and flying foxes the four innermost fingers, or three of them at least, are almost as long as the arm and the forearm put together. Only the thumb remains short. It ends in a powerful claw which is used by the animal for climbing, and when hanging in a state of repose. The wing is a membrane stretched between the long fingers of the fore-limb and the long toes of the hind-limb.

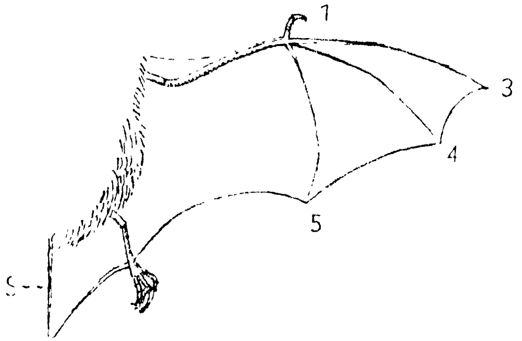

Fig. 25.—Wing of a Bat (Vespertilio murinus).

1, first finger (thumb): the fore-finger is not seen; it lies close to the thumb. 3, 4, 5, the respective fingers. S, tail.

Flying Saurians

The problem of featherless flight was solved in kindred fashion by the flying saurians of the Trias, which improved upon their first ventures subsequently, during the Jurassic and the Cretaceous, though it is doubtful if they ever flew as well as the bats and flying foxes of to-day. Their remains vanish with the end of the Cretaceous, at the time when the conquest of the air was being more widely extended by birds and flying mammals. In the flying saurians (the pterodactyls, ranging in size from that of a sparrow to that of a raven, many of whose skeletons have been preserved in the lithographic laminated Cretaceous of Bavaria; and in the huge pteranodon of the later American Cretaceous, which had a wing-span of nearly thirty feet), the levers for the tensing of the wing-membranes were likewise obtained by an enormous lengthening of the fingers—in this instance confined to the last of the four remaining fingers (i.e. the "little finger"), whereas the index, middle, and ring fingers remained short, and ended in claws. The thumb or first finger had been suppressed. The wing membranes stretched from the elongated "little fingers" to the hind feet. The size of the wings might lead us to fancy that these saurians were good fliers, were it not that the poor development of the breast-bone shows that they could not have had powerful pectoral muscles. It is doubtful therefore whether, like birds and bats, they could sustain themselves in the air. More probably they were gliders like the contemporary flying squirrel, Draco volans, etc.

Lamarck

When you ponder the way in which originally identical skeletal elements have been modified for the performance of such diversified tasks, and when you recall how in animals so widely distinct as the flying mammals are from the flying saurians, like functions have called forth like structures, you will readily understand why Lamarck was led to formulate his theory of the evolutionary working of use and disuse. But, as I have already told you, the question upon the answer to which the Lamarckian theory stands or falls is whether changes brought about in any organ through use or disuse are transmissible by inheritance to the offspring of those in whom such changes have occurred. In a word, are acquired characters inherited or are they not? This is a matter which will come up for careful consideration in due course.

B.—When I learn how purposively nature works, how seemingly blind activities produce such beautiful works of art, I feel a solemn emotion such as inspires me when contemplating a Gothic cathedral. I simply cannot understand how the study of natural science can incline any one towards materialism.

A.—Thanks be, the days when Büchner's *Force and Matter* and Haeckel's *The Riddle of the Universe* could lead people's thoughts astray, are long since over. You will find some of the most ardently religious men among the scientists. Darwin himself was a believer. Since change of function plays so important a part in evolution and in modifying structure, I should be glad to refer to an expansion of function that has occurred in the bats; but it is so late that we must wait till to-morrow.

EIGHTH EVENING

HORMONES

Expansion of Functions in Bats

B.—You said you were going to tell me about an expansion of functions in bats.

A.—Yes. As you know, in most mammals the external ears serve to receive sound-waves and to direct these towards the ear-drums. An accessory use of the very large ears of donkeys, horses, and bovines is that their twitching movements scare and shake off molesting insects. In bats, likewise, the gristly external ears are very large, but have little mobility. They are, however, beset with numerous sensory cells, thanks to which they have become extremely delicate sensory organs, which react to the most trifling changes in air-pressure and warn the creatures as soon as they are approaching solid objects. The wing membranes have the same keen tactile sensibility, enabling bats (even when blinded) to fly among stretched wires without ever colliding. You see once more how an organ which originally came into being for another purpose can undergo modifications that fit it for a new function. Sometimes the original function will pass altogether into abeyance, and the new function will become exclusive. Such a change of function, with the structural changes it induces, plays a decisive part in the gradual transformation and evolution of animals and plants. Do you understand my drift ?

Organs are thrown out of Gear

B.—I think so.

A.—Well, then, answer me this question. Let us suppose that a bay is cut off from the sea, and that by a further elevation the water is slowly transformed into dry land. The animals living there have less and less opportunity for continuing the original function of organs primarily adapted to a subaqueous life. What will happen to the parts thus thrown out of gear ?

B.—They will atrophy and disappear.

The Swimming-Bladder once more

A.—That may happen, but it is not inevitable. Have you forgotten what I told you about the swimming-bladder of fishes ? Originally it was a hydrostatic apparatus, enabling its possessor, without undue expenditure of energy and by a simple modification of specific gravity, to swim at various depths. When the mud-fish took to a terrestrial life, this hydrostatic function of the swimming-bladder became superfluous. But the organ persisted, having taken on new duties. Its inner surface was more richly vascularised, for the better absorption of oxygen from the air, and began to function as a lung. (See Fig. 33, below.) Let us take another example. If a muscle is put completely out of use, the muscular tissue soon disappears. But the vascularised connective tissue remains, and can be turned to other uses, as when it is converted into a tendon, which gives another muscle a firmer or more advantageous attachment to a bone. A third instance will make the point even clearer. In all

ORIGIN OF THE THYROID

the higher vertebrates, man included, there is situated in the front of the neck a gland known as the thyroid, one of the glands of internal secretion (also called endocrine glands). This gland plays a very important role in the economy of the organism. The gland cells

THE THYROID AS MOTOR AND AS BRAKE

of the thyroid secrete an iodine-containing substance, called iodothyreoglobulin. It is poured into the blood, and has the remarkable power of stimulating the functions of certain organs and of inhibiting those of others. Operative removal of the thyroid, such as in former

GOITRE AND GRAVES'S DISEASE

days was sometimes effected for the relief of wen or goitre, is followed by a general slackening of tissue-change, which shows itself in the form of very serious symptoms. If the thyroid is excised in early childhood, there ensues an arrest of growth, and the gradual onset of idiocy. In grown-ups, destruction, excision, or arrest of function of the thyroid results in a gradual loss of power and failure of general nutrition (cachexia) accompanied by a distension of the subcutaneous tissue with mucin-containing serum and by the onset of dementia. The whole symptom-complex or syndrome is called myxœdema. If, on the other hand, the thyroid enlarges and pours an excess of its specific incretion into the blood, there ensues a morbid intensification of metabolism and the symptom-complex known as exophthalmic goitre or Graves's disease. In this illness, when the thyroid is enlarged and functions to excess, excellent results can be obtained by the operative removal of part of the hypertrophied gland.

RE-FORMATION OF LOST PARTS

Many animals, even some that stand high in the zoological scale, have in youth a faculty of reproducing lost parts by the process termed regeneration. Indeed, unless birds and mammals (though they cannot replace a lost limb) retained some of this capacity for regeneration, wounds would never heal. In salamanders, which are at a " lower " level, if a limb be bitten off, a new one sprouts in its place. But if the animal's thyroid has been removed, no regeneration of the lost limb occurs—unless you give the sufferer the thyroid of other animals as part of its daily diet, for then the regenerative faculty is reactivated. In experiments on animals, in such cases, good results have also been obtained by the transplantation or ingrafting of thyroid tissue. Similarly in man. In a cretinoid child four years of age Payr grafted into the spleen part of the mother's thyroid, whereupon the girl, previously idiotic and unable to walk, began to develop both physically and mentally, soon learning to walk and talk. Unfortunately such successes have not hitherto proved durable in human beings.

B.—Am I to understand that this important organ originally had different functions, and has been diverted from something else to its present uses ?

TUNICATA

A.—To make the matter plain to you, I must take you somewhat farther afield. When visiting an aquarium, you must have been struck by the remarkable organisms known as sea-squirts or ascidians, fattish looking creatures, white, brown, or red in colour, attached to stones. The body is enveloped in a dense, transparent, gelatinous mantle or tunic, whence the class of animals equipped with this covering has been called the tunicata. The layman hesitates to regard sea-squirts as animals, so firmly are they rooted each to one spot. Close investigation shows, moreover, that they have another peculiarity which belongs rather to the vegetable kingdom than to the animal. The mantle consists mainly of cellulose or of a substance closely akin thereto ; and cellulose (which is the main ingredient of timber) used to be regarded as a purely vegetable product. Nevertheless the tunicata (to which the mobile salpidæ and also the tailed free-swimming appendicularia belong) are really animals in respect of organisation and mode of nutrition. Formerly they were regarded as the ancestors of the vertebrate stock, but are now believed to have diverged from the main line of descent just before vertebrates came

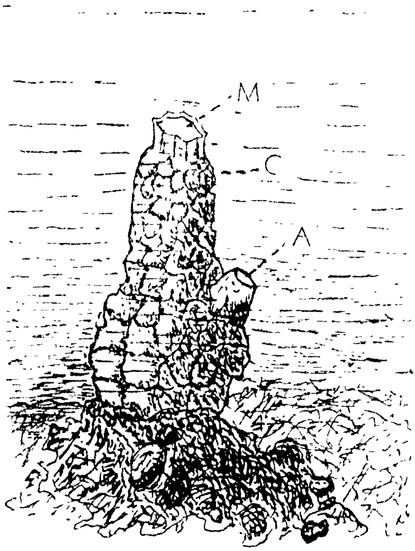

FIG. 26.—THE TUNICATE ASCIDIAN, ASCIDIA MAMMILLATA.

M, mouth ; A, anus ; C, cellulose mantle.

CELLULOSE IN ANIMALS

NOTOCHORD AND SPINAL COLUMN

into being. In their free-swimming larval state the tunicata have in their tails a cartilaginous axis, the chorda dorsalis or notochord. A notochord is also found in the amphioxus or lancelet and in lampreys. By gradual segmentation and ossification, in the course of phylogenetic development the vertebral column of the higher vertebrates developed out of the notochord. (See Fig. 27.) But this is not a matter now to be discussed in detail.

THE ENDOSTYLE

I have only introduced it in order to lead up to the origin of the thyroid, which derives from a very different organ possessed by the sea-squirts. In the lining membrane of the ascidian pharynx, we find a fold containing mucous glands and covered with ciliated epithelium; this organ, known as the endostyle, has the funtcion of grasping the fragments of food contained in the water which is ingested for respiratory purposes and of passing them on into the hind-gut. In the higher vertebrates we look in vain for any organ resembling the endostyle.

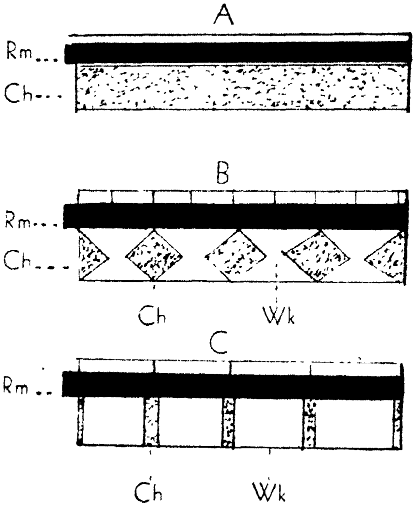

FIG. 27.—DIAGRAM TO SHOW THE PHYLOGENETIC ORIGIN OF THE SPINAL COLUMN.

A, in the lower cartilaginous fishes; B, in the higher fishes and the lower reptiles; C, in mammals. Rm, spinal cord; Ch, Notochord, Wk, vertebræ.

AMMOCOETES

In ammocoetes, however, the youthful form of the lamprey, we find in the same region of the pharynx a strip of quite similar cells. As the ammocoetes grows up into a sexually mature lamprey, this group of cells develops into a comparatively large ductless gland, in fact into the thyroid.

B.—You forget, sometimes, that I have had no medical education, so that much which is A B C to you is Greek to me. What are glands of internal secretion, and what are the mysterious substances they supply to the blood?

GLANDS AND THEIR FUNCTIONS

A.—Glands are cells or aggregations of cells which secrete the various gases, fluids, and solids that do not become permanent parts of the organism, nor yet of the glands themselves, but serve the needs of the organism in various ways.

B.—Please give me some examples of their functioning

A.—The fields of glandular activity are so diversified, that the mere enumeration of them would take hours. To mention a few, there are: the lacteal glands which in mammals serve to nourish the young; the sweat-glands, by which the temperature is regulated; the sebaceous glands which grease the skin and the hair; the salivary glands which supply the mouth with spittle; the pancreas; the pepsine-glands of the stomach; the liver; and various other digestive glands. Then there are glands which serve the purposes of offence or defence: such as the poison-glands of serpents, bees, etc.; the stink-glands of the skunk; and the ink-glands of cuttlefish. Other glands subserve locomotion: among these being the mucous glands that lubricate the snail's foot; and the glands which supply the feet of many insects with a sticky secretion, rendering it possible for the creatures to crawl up smooth surfaces, or even to crawl on a ceiling. Yet other glands, such as the odoriferous organs of butterflies, and the musk-glands of the musk-ox, the crocodile, and many bats, secrete sexual lures. The glands that make fire-flies luminous fulfil a like function. The fine threads out of which the garden spider makes its web, and the thread spun by the silkworm when it makes its cocoon for the protection of its chrysalis stage, are also glandular secretions. In a word, there is scarcely a single domain of life in which glandular activity does not play an important role.

The Gonads or Reproductive Glands

B.—You have not mentioned the germinal or reproductive glands.

A.—Not yet, but these gonads (as they are technically termed) are reckoned among the glands, although their most obvious function is to produce, not secretions, but living cells. But, in addition, the interstitial tissue of the reproductive glands supplies important stimulating substances to the blood, the sexual hormones which are in the focus of physiological interest to-day. These sexual hormones have a far-reaching influence upon the causation of sexual maturity, upon the development of the secondary sexual characters, the growth of the female breasts, the sprouting of the beard and the pubic and axillary hair, the onset of the colouration which distinguishes males and females during the adult life of many species, etc.

B.—It would seem that the study of the glands and their secretions must be a job for a specialist.

Glands of Internal Secretion

A.—I have only touched the fringe of the subject so far. I am coming now to the answer to your main question. According as the substances produced by the cells of a gland are turned to useful account by an organism, or are merely by-products of tissue-change of which the body has to rid itself as useless and often positively harmful, we speak of them as secretions in the former case and excretions in the latter. But whereas all the glands I have hitherto mentioned produce secretions (substances directly valuable to the organism), the kidneys, for instance, the paired glands which separate urea,

NOTOCHORD AND SPINAL COLUMN

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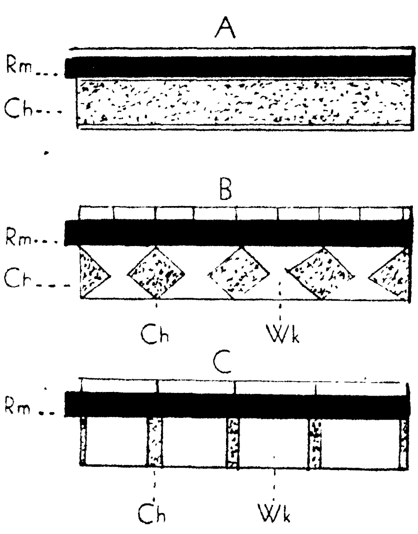
THE ENDOSTYLE

AMMOCOETES



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B.—Why do you distinguish certain glands as glands of internal secretion ? Surely all secretions and excretions are prepared in the interior of the gland cells ?

A.—You are quite right. Whereas, however, the exocrine glands or glands of external secretion pour their characteristic products through a duct opening upon the surface of the body or into one of its cavities, the endocrine glands or glands of internal secretion have no ducts, but pour their specific substances (often called, for short, their " incretion ") directly into the blood, which then carries it to the various parts of the body which have need for it. The foregoing distinction cannot, indeed, be firmly sustained, for many exocrine glands have also an endocrine function. Glands are excretory, secretory, or incretory. The ductless glands are exclusively incretory ; but many of the ducted glands are both incretory and secretory. Thus the term " endocrine gland " is not synonymous with " ductless gland " ; the former term concerns function, the latter concerns

The Pancreas

structure. Consider now the pancreas, for instance, which delivers through the pancreatic duct into the intestine an external secretion containing ferments able to split up fats into glycerine and fatty acids. This gland has lying between its secretory lobes remarkable structures composed of cells very different in appearance from the ordinary secreting cells. These groups of cells are called the islands of Langerhans, and their function was not elucidated until a few years ago. The islands furnish an internal secretion containing an active principle, insulin, which Banting and Best were the first to

Diabetes and Insulin

separate out as a pure concentrate. This hormone regulates the sugar metabolism of the body. A slackening in the formation of insulin, and the consequent disorder of sugar metabolism, give rise to the dreaded disease diabetes mellitus. In the healthy body, the production of insulin proceeds regularly, so that the sugar-content of the blood is kept at a proper level. An excess or defect in the production of insulin will lower or raise to a serious degree the percentage of sugar in the blood, with resulting grave disorders of general metabolism or tissue-change. You probably know that in diabetics wounds heal slowly if at all, so that operations on these sufferers are exceptionally dangerous. By the artificial supply of insulin, the percentage of sugar in the blood can be reduced, and thereupon the wound (accidental or operative) begins to heal in normal fashion.

Purposiveness

B.—After listening to what you have said, it seems to me as if the human body had been as purposively constructed as the most delicate and intricate machine. How could the blind working of inorganic forces possibly lead to such technical perfection ?

A.—Still, you must walk warily in applying this notion of purpose to the consideration of physiological processes. Beyond question insulin is of vital importance to the bodily economy, but we have no warrant for asserting that it was designedly produced for the express object of regulating the sugar-chemistry of the animal body. That would be to introduce the human notion of purpose into the machinery of natural workings. Coke was originally a by-product formed when coal was heated in a confined space for the production of illuminating gas. Nowadays illuminating gas is little used, whereas coke is of importance as smokeless fuel and in various industrial operations. Coke is therefore the main-product, in our own time, of the destructive distillation of coal, and a somewhat different oven is used to furnish a better quality of coke. But illuminating gas appears as a by-product; and there are various other by-products, such as coal-tar which is the source of benzol, the aniline dyes, etc., made out of what was for a while regarded as a waste-product. In like manner, insulin may have originally been no more than a by-product or waste-product of the primary glandular activity of the pancreas as a digestive gland. By chance it may have happened that it exerted a beneficial influence upon the sugar-metabolism of the body, which had previously been regulated in some other way. This is purely hypothetical, but I trust it will help to illustrate my train of thought.

MAIN-PRODUCT AND BY-PRODUCT

B.—The coke parallel is certainly instructive. But are there any indubitable instances in which a waste-product of tissue-change has been turned to useful account?

CARBONIC ACID AND THE RESPIRATORY CENTRE

A.—There are many. Here is one. In every metabolic process, carbonic acid is formed, for life is a slow combustion of carbon compounds. Tissue-change or metabolism consists of two phases, anabolism or building-up into tissue and katabolism or the breaking-down of tissue into residues and slags. Carbonic acid is a typical katabolic product; but nevertheless it fulfils an important function by its presence in the blood, inasmuch as, like a hormone, it exerts a stimulant action—upon the respiratory centre of higher vertebrates.

HORMONES

B.—Why are the glandular incretions of which you have been speaking styled hormones, exciters, or stimulants?

A.—Because they function as specific stimulants of the growth and activity of organs which are often situated in parts of the body remote from those in which the hormones originate, and the organs stimulated by them cannot do their work properly, or cannot develop properly, unless so stimulated. Starling, therefore, aptly called the hormones "chemical messengers", since, like messengers, they are sent out to fulfil an important commission. In some instances, a hormone does not arise in the organism where it fulfils its tasks, but emanates from a distinct organism. If, for example, a pregnant woman's pancreas should become unable to perform its duty as controller of saccharine metabolism, the fœtus may supply the requisite insulin. Remind me, in due course, to give you a still more striking instance from the life-history of Bonellia viridis.

B.—I thought that stimuli were only conveyed through the instrumentality of the nervous system.

WIRED AND WIRELESS TELEGRAPHY

A.—That view is out of date. We know to-day that, in addition to nerve-telegraphy, which is, so to say, " wired ", the organism has a chemical or " wireless " system of telegraphy to regulate the teamwork of the various organs. Why do the mammary glands not begin to secrete milk until a woman becomes pregnant? Because not until then are the specific stimulants which arouse this activity formed in the interstitial tissue of the ovaries. Starling and Clayton have shown that the developing embryo also forms a galactagogue hormone which passes through the placenta into the maternal circulation, and, on reaching the breasts, induces enlargement and the secretion of milk.

THE GALACTAGOGUE HORMONE

B.—How can it be proved that the stimulus is not conveyed by the nervous system?

A.—First of all, as regards the galactagogue hormone produced by the embryo, there is no nervous connexion whatever between the embryo and the mother. Secondly, when a mammary gland is excised, all its nervous connexions being consequently severed, and it is then ingrafted into some other part of the body, it begins to secrete milk towards the end of pregnancy.

B.—That is most interesting.

A.—Even more interesting is the close interdependence of the various endocrine glands. I have already told you of the disastrous effects of excising the thyroid. If you like, I will go more fully into the working of the thyroid.

B.—Of course I should like!

THYROID AND TESTICLES

A.—Well, the thyroid incretion stimulates the formation of the testicular hormone, which is indispensable both to the production of the semen and to the development of the secondary sexual characters. In certain affections of the thyroid, the male gonads continue rudimentary, no spermatozoa are formed, the sexual impulse is in abeyance, and the secondary sexual characters atrophy. Experiments on animals show that the disease of the thyroid is indirectly responsible for the morbid symptoms in the sphere of the sexual life. On the other hand, when raw thyroid or thyroid extract is fed to young animals, a premature sexual development ensues. If you administer thyroid tablets to cockerels, the young birds will develop combs,

SEXUAL PREMATURITY

spurs, cock's plumage, etc. much earlier than control birds from the same clutch to which no thyroid is given. Since thyroid extract has no such effect on birds whose testicles have been removed, we infer that the premature sexual development is not directly due to the thyroid hormone, but indirectly to the manner in which it stimulates testicular activity.

EFFECTS OF CASTRATION

B.—I suppose, then, that the deviation from the type of the entire male that is noticeable in castrates is due to the absence of the stimuli that would have been poured into the blood had not the glands been removed ?

A.—Yes.

B.—Why, then, as an outcome of castration, does the male body become feminised and the female body masculinised ?

[The translators follow the convenient German usage of applying the term "castration" indifferently to the removal of the gonads in either sex.]

A.—The facts are not correctly described. Really, the male castrate is not feminised, but is of an undeveloped, infantile type. The beard and the pubic and axillary hair fail to grow; and the larynx remains infantile, so that the treble voice of the child persists in the adult eunuch. (Soprani and alti castrati.) Eunuchs also incline to put on fat. It is only because in women, as contrasted with men, the infantile type is normally in great measure retained, that the inhibition of growth in male castrates gives them a pseudo-feminine aspect. Nor are we entitled to describe as masculinisation the changes of type characteristic of castrated women.

B.—The matter is not quite clear to me yet.

INHIBITION OF THE DEVELOPMENT OF SECONDARY SEXUAL CHARACTERS

A.—An example from the lower levels of the mammalian kingdom will help you to understand that the most conspicuous effect of castration is the inhibition of the development of secondary sexual characters. In reindeer, bovines, and certain kinds of sheep and goats, there is little difference in the size of the horns or antlers in the respective sexes. In such creatures, castration has little effect upon the development of these ornamental or combative organs. But if you castrate a stag, whose antlers are certainly a specifically male character, the antlers will fail to appear. Not all the secondary sexual characters, however, are subject to the influence of the sexual hormones. The canine teeth of a gelding, for instance, are quite as large as those of a stallion.

B.—I suppose castration after puberty, when an animal is almost grown up, has no effect on the secondary sexual characters ?

A.—It has effects, but they are less marked. In a stag whose antlers have already sprouted, castration causes aberrations in the periodicity of shedding, or gives rise to malformations, such as the growth of what are known as peruke antlers.

B.—Have any other hormones an influence on the reproductive glands ?

Thyroid and Metamorphosis

A.—Go slow! We have not finished yet with the workings of the thyroid. You are familiar with tadpoles, water-dwellers, which only develop into young amphibious frogs through an extensive metamorphosis in which their gills atrophy and they lose their tails. If you feed thyroid extract to tadpoles, you will greatly accelerate this metamorphosis. If, on the other hand, you excise a tadpole's thyroid, metamorphosis will not take place. The animal will go on growing, but will develop into a giant larva, not into a frog. A larval salamander of the same sort—the Mexican axolotl, which normally fails to achieve its metamorphosis, spends its whole life in the water, but becomes there sexually mature—is a favourite denizen of our aquariums. It is plain that this arrest of development in axolotl is due to atrophy of the thyroid, for if you feed thyroid to young axolotl larvæ they undergo metamorphosis into a land-dwelling salamandrine form, Amblyostoma tigrinum.—I think you had another question in view?

B.—Yes, I should like to know whether other incretions than the thyroid have an influence upon the reproductive glands and the secondary sexual characters.

Pineal Gland and Pituitary

A.—Such an influence is exerted by two of the appendages of the brain, the pineal gland and the pituitary.

B.—Oh, these technical terms!

A.—Have patience. I am about to explain them. We will first consider the still obscure functions of the pineal gland, which in ancient times was regarded as the seat of the soul. In man it is a stalked structure, about two-fifths of an inch in diameter, perched upon the upper surface of the brain amid the corpora quadrigemina. Phylogenetically it is the vestige of a third eye, which, in the course of the genealogy of the various species has completely lost its visual function. Only in the lamprey and in the New Zealand tuatara has this frontal or cranial or cyclopean eye persisted, though in a rudimentary form. The extinct ancestors of our amphibians and reptiles also had such a cyclopean eye, in their case fairly well developed. Though vestigial, the pineal gland is not a useless structure like the vermiform appendix of the cæcum, having undergone a change of function to become an endocrine gland. We know this much, that the pineal hormone has an inhibitory influence upon the growth of the testicles, and thus upon the appearance of the secondary sexual characters. After its operative removal in cockerels, Foa was able to detect an unmistakable acceleration of the growth of the testicles and of the comb. In the sexual prematurity of boys (pubertas præcox), in whom a ripe sexual development, accompanied by the growth of the beard and the pubic hair and the breaking of the voice may sometimes occur in early childhood, it has, on the other hand, been found that as a rule the pineal gland has been destroyed by a tumour (a teratoma). In contrast with the pineal gland, the pituitary, a glandular structure attached to the base of the brain, produces hormones that markedly stimulate growth and the onset of sexual maturity. This is especially clear in females. The pituitary incretion is therefore regarded as the inciter of ovulation, inducing the ova to ripen and menstruation to begin. These two glands, therefore, the pineal and the pituitary, play opposing roles in the animal economy.

B.—Please tell me more about the pituitary ; its size, its situation, and its structure.

A.—The pituitary is a trilobate organ, consisting, developmentally considered, of two parts, one of these being a diverticulum from the top of the pharynx, and the other an outgrowth from the nervous system, from the part of the brain known as the infundibulum. Its size is that of the finger-tip.

Effects of the Pituitary Hormones

More important than these anatomical details, however, are the physiological effects of the pituitary hormones. The three lobes secrete different active principles. The most striking effect of the pituitary hormones is the way in which they promote growth. Dogs whose pituitary has been removed when they are about six weeks old have their growth so much arrested that several months after the operation their weight will be no more than a fourth or a third of that of another puppy of the same litter on which no operation has been performed. But the normal proportions of the skeleton will remain. Another developmental disturbance resulting from removal of the pituitary is that the milk-teeth are not shed, but persist through life. Sometimes, indeed, the permanent teeth are cut beside the milk-teeth, so that the animal has a double row. The delicate hair of early youth also remains. The animals without a pituitary have a strong tendency to put on fat, sometimes developing a panniculus adiposus an inch or more in thickness ; and the internal organs become surrounded with thick layers of fat. Most noteworthy of all the changes caused by early removal of the pituitary is the arrest of growth in the reproductive glands, male or female as the case may be ; with a consequent failure of the secondary sexual characters to appear, and an abeyance of the sexual impulse. Manifestly the growth-promoting hormones are incretions of the anterior

Nanism and Gigantism

lobe, for any disturbance of the functioning of the " anterior pituitary " (as it is sometimes called for short) in early life leads to dwarfing, or nanism, even though the posterior lobe be unaffected. On the other hand an excessive supply of pituitary hormones causes an exaggerated growth in the length of the bones, and thus induces gigantism.

B.—A fuller explanation of this matter would be helpful.

A.—A tubular long bone in a vertebrate consists of three parts : a middle portion, the shaft or diaphysis, in which ossification begins ; and two ends or epiphyses which, until growth is finished, are not ossified to the shaft, being connected to it at each end by a disc of cartilage known as the epiphysial disc. It is in the epiphysial discs that growth in the length of the limbs proceeds until full stature is attained. Then they, too, become bony.

B.—How was it discovered that pituitary hormones stimulate growth ?

A.—Evans succeeded in obtaining a fairly pure preparation of the anterior pituitary hormone. Administering this to young rats, he produced giant specimens. Their epiphysial discs did not become ossified at the usual age, and the long bones went on growing. There is a disease known as acromegaly in which the bones and other tissues of the hands, face, and feet are enlarged. It is usually associated with gigantism. In most cases, whether in men or in women, it sets in between the ages of twenty and thirty ; and in almost all the cases in which a post-mortem examination has been possible, there was found a tumour-like enlargement of the anterior pituitary. If the trouble begins before the ossification of the epiphysial cartilages has taken place, i.e. before the patient is fully adult, gigantism is its most obvious result. When it arises later in life, it leads to hypertrophy, sometimes of the lower jaw, sometimes of the hands or the feet, sometimes of the lips and the tongue (magroglossia), and sometimes of one or more of the internal organs. If the diseased anterior pituitary be successfully removed at an early stage, the secondary symptoms will subside.

The Skoptsy

There are close relationships between the pituitary and the gonads. Removal of the testicles in early youth, as was done by members of the Skoptsy sect, often results in the boys thus treated becoming excessively tall. On the other hand, growth in stature usually ceases at or soon after puberty, when the reproductive glands take on the functions proper to adult life, so that there is good reason to believe that the gonads produce an incretion which counteracts the effects of the anterior pituitary growth-promoting hormone.

Causes of the Maturation of the Ovum

B.—Why did you say, a little while ago, that the pituitary hormone was the exciting cause of the maturation of the ovum ? I thought maturation of the ovum was brought about by an ovarian incretion.

A.—Such was the general belief until, recently ; the researches of Zondek and Aschheim showed that there is a remarkable interlinking of anterior pituitary and ovarian activity. The ova ripen in little sacs called Graafian follicles, and these follicles contain a hormone known as the follicular hormone. If in a young female mammal some of this follicular hormone obtained from an older female be intra-muscularly injected, a premature rut occurs in the young female, and frequently repeated injections will keep it in a state of continuous rut. The uterus enlarges, its mucous membrane thickens and becomes

Artificial Rut

fitted for the implantation of a fertilised ovum. On the other hand, the ovaries of a young female thus treated remain in the infantile stage, being uninfluenced by the follicular hormone. Obviously, then, there must be formed in the body some other hormone, either competent unaided to induce the maturation of the ovum, or else capable of stimulating the ovarian hormone to this activity. After lengthy researches, these two investigators were able to discover in the incretion of the anterior pituitary the " over-riding " general sexual hormone of which they were in search. For if to a young female being treated with follicular hormone, anterior pituitary hormone be simultaneously administered, a full sexual maturity, namely rut, accompanied by maturation of the ovum, will ensue.

B.—Perhaps, when that happens, the anterior pituitary hormone is the sole active agent in bringing about the ripening of the ovary, and the follicular hormone plays no part ?

A.—This objection can also be refuted. If the anterior pituitary be excised, maturation of the ova ceases to occur, the ovaries become quiescent, and should there happen at the time of operation to be a fertilised ovum that has nested in the wall of the uterus, this ovum will perish and be discharged. Furthermore, Boeters and Zondek, by administering anterior pituitary hormone to an infantile animal, were able to induce the maturation of an ovum and to ensure its fertilisation—in a word, to bring about an artificial pregnancy in an immature female. Herein we have unimpeachable evidence that this anterior pituitary hormone, which passes by the name of prolan, is really the over-riding sexual hormone. The intimacy of the relations between the gonads and the pituitary is likewise shown by the fact that castration is followed by an over-production of anterior pituitary hormone. But the hormone thus produced is incompetent to cause rut in the castrated organism, and is, therefore, not fully effective. Zondek and Krohn also succeeded, by injecting prolan into a little fish (Phoxinus laevis), in producing artificially the red colour of the scales which is proper to the male fishes in the spawning season.

HORMONES ACT IN OTHER ANIMALS THAN THEIR PRODUCERS

B.—Then the hormones of human beings are effective, not only in human beings, but in other animals as well ?

A.—Yes, hormones are in this sense no more " specific " than are vitamins. They are chemical substances produced by various kinds of organism, but having the same composition in each. Pancreatic insulin is also found in various bulbs. In like manner Loewe, Faure, Poll, Molnar, and others, have found in potatoes, turnips, yeast cells, and bacterial cultures, a hormone identical with the follicular hormone. Aschheim was actually able to show that this hormone can be extracted from lignite, which means that it can have a stable composition for many thousands of years. Probably the function of the hormone in plants is merely to accelerate growth ; for, as Schoeller has found, premature blossoming can be brought about in plants by the ingestion of follicular hormone.

DIAGNOSIS OF PREGNANCY

B.—I seem to remember having read somewhere that by the use of hormones it is possible to ascertain earlier than in any other way whether a woman is pregnant or not.

A.—Yes, that is another of the discoveries of Zondek and Aschheim. From the second month of pregnancy onward, there is invariably present in a woman's urine a substance which has exactly the same effect as prolan. Young mice treated with this substance display typical manifestations of sexual prematurity. Thus from the time when a woman's menstruation is six days overdue, it is possible by the Zondek-Aschheim urinary hormone test to ascertain whether the non-appearance of menstruation is due to pregnancy. The explanation is that throughout pregnancy there is over-production of follicular hormone, and the excess finds its way into the urine. Nowadays the follicular hormone needed for therapeutic purposes is chiefly obtained from the urine of gravid mares. Such follicular hormone has the same effect as prolan in stimulating the growth of plants.

STIMULATION OF GROWTH IN PLANTS

B.—Then the farmer folk who stubbornly insist that natural manures are better than artificial, are not so reactionary as they seem, and science has found justification for their " prejudices " ?

A.—Yes, it is true that the study of hormones has shown that the peasants were not far wrong. Even though an artificial manure may seem to have a chemical composition closely resembling that of natural manure, the latter is preferable because it contains prolan and folliculin. But I think you have heard enough about glands and their functions.

BONELLIA VIRIDIS

B.—You said I was to remind you about bonellia.

A.—The reminder comes at an appropriate moment, though it is nearly time to close this evening's session. Bonellia viridis, which abounds on the shores of the Atlantic Ocean and the Mediterranean, is indeed a strange creature. The males and the females are so markedly different as to form one of the instances of what is known as sexual dimorphism. The body of the female is a plump muscular sac, sometimes spherical and sometimes ovoid, four or five inches long. (See Fig. 28.) From this there projects a sort of proboscis which may stretch to a length of twenty inches or more, ending in a mouth that opens between cephalic lobes. The males, on the other hand, are tiny creatures whose dimensions can only be given in millimetres. We usually find a number of them looking like parasites infesting the female genital aperture. Another peculiar characteristic of bonellia viridis, its vivid green colour, is implied

SEXUAL DIMORPHISM

DWARF MALES

in its name. Like all the higher animals, bonellia produces ova, which are fertilised in the vagina of the females by the dwarf males. Out of the fertilised ova develop free-swimming ciliated larvæ which are, to begin with, perfectly neutral in the sexual respect. Whether such a larva develops into a dwarf male or a giantess, depends upon its subsequent course of life, which is more or less a chance matter. The germ-plasm of the larva contains the rudiments necessary for the production of either sex. In most sexually differentiated animals, the determination of sex is effected at fertilisation ; but in bonellia, much later.

Determination of Sex

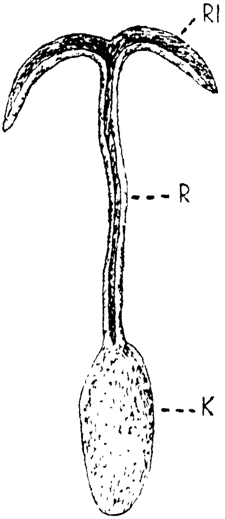

Fig. 28.—Female Bonellia Viridis.

K, body ; R, proboscis ; Rl, Cephalic lobes.

B.—That is very strange.

A.—In this respect, bonellia is not altogether exceptional, for there are other exceptions to the law just formulated, other creatures in which a deferred or metagamic sex-determination occurs. But the reason why bonellia especially interest us in this connexion is that the decision whether one of the free-swimming larvæ becomes a male or a female depends upon the working of a hormone. That, I have already said, is decided by chance. If the larva, during its wanderings, should fail to encounter the proboscis of an adult female on which it can settle down, it must abandon its hopes of ever becoming a male. As long as nothing was known about hormones this matter remained obscure. To-day, however, we know that the superficial cell-layers of the female bonellia's proboscis produce a hormone which inhibits the development of the feminine rudiments of the larva and stimulates maleness. But the male tendency is not effectively promoted unless the larva is exposed to the working of the hormone for a sufficiently long time. If you remove a larva from the female's proboscis within twelve hours, it will still grow into a normal female ; but if it be left undisturbed upon the proboscis longer than two days, it will infallibly develop into a male.

B.—What happens if the larva be removed after more than twelve hours and before two days have elapsed ?

Artificial Hermaphrodites

A.—Such larvæ become hermaphrodites, to a degree which varies in its completeness according to the time the larva has spent on the female proboscis. The shorter the time, the more marked the tendency towards femininity ; the longer the time, the greater the emphasis of masculine characteristics. In recent experimental work, extractives have been produced from dried probosces ; and with the aid of these, larvæ which have never come into direct contact with a female have been forced to become dwarf males.

Bees

B.—As you know, I keep bees. In these insects, the decision whether eggs develop into males (drones), or into females (queens or workers), depends upon whether the ova are left unfertilised or are fertilised. Whether a fertilised ovum grows up into a queen or a worker is at the discretion of the extant workers in the hive, who put the ova that are to become queens into larger " royal ", cells, and feed the " royal " larvæ on richer food. Should the queen of a hive die, and no successor be available, the workers can enlarge a worker cell into a royal cell and by richer feeding transform the worker larva into a queen. The richer food thus fed to the larva acts like a hormone.

A.—I see you have observed your bees carefully. It is generally believed to-day that the " royal jelly " on which the larvæ intended to become queens are fed has been enriched by a true hormone derived from the salivary glands of worker bees and mixed with the pulped food. When this saliva is not mixed in, the food will only produce workers. Bethe and other investigators are inclined to extend the hormonic concept to include the substances excreted as sexual lures by many animals at the rutting-season—substances which serve to intensify the sexual impulse and help the members of the respective sexes to find one another. To how great a distance the working of these sexual lures extends, can be well seen in the case of butterflies and moths. If you cage a female butterfly in a room with an open window before long as many as a hundred males of the same species will flutter in through the window. Standfuss caged a female Smerinthus ocellata at a distance of more than a mile from its male partners. Within six minutes the odoriferous lures had attracted the males to the spot. Guided by their olfactory organs they had sought their goal with the speed and certainty of a motor car. Yet these odours are so faint that our coarse sense-organs cannot perceive them. Faber caged female butterflies in a room where the air was tainted with strong, offensive smells ; nevertheless the males sought the females out, unperturbed by the " stinks ".

Sexual Lures

The Common Crab

Another very characteristic example is that given by Bethe of the common crab. The female crab is only disposed for sexual congress immediately after casting her shell, and only at this time do her rutting-glands secrete their odoriferous lure. When her new shell has hardened, the males pass her without heeding ; but if a female that has just cast her shell be placed in an aquarium, all the males become greatly excited, and give chase to her. It suffices to throw into the aquarium a scrap of cloth with which the shell of such a female has been wiped, to produce the same excitement in the males. Whether we choose or do not choose to include such sexual lures under the concept " hormones " is purely a matter of the definition of that term. We may widen it or narrow it as we please. Enough of this.

Attempts at Rejuvenation

B.—Of late years there has been much talk concerning experiments aiming at rejuvenation. Does this come within the chapter " hormones "?

A.—Yes, but much of the matter remains so obscure that a genuinely scientific exposition is still difficult. Among the uninstructed, such exaggerated notions have been diffused that I shall content myself with a brief account. That, at least, is desirable, to counteract prevailing errors. Just as the summer of life begins with the ripening of the gonads, the testicles or the ovaries as the case may be ; so with the decline in the functional activity of these glands as age advances, does the autumn of senility set in. This is not a chance association, for the hormones poured into the blood by the reproductive gland have cogs interlocking with the whole physiological machinery, upon whose working they exert a regulative influence. It seems reasonable, therefore, to regard the ageing of the gonads as the cause of the onset of senility. It was under the guidance of this hypothesis that certain investigators set to work upon experiments designed to stimulate the enfeebled gonads to renewed activity, or to administer to an individual in whom senility was beginning the sexual hormones derived from a younger and more vigorous organism; in the hope that this might give a new lease of life. The pioneer in this field was the famous physiologist Brown-Séquard (1817–1894, born in Mauritius, professor in America and in Paris, of mixed nationality like his name), who injected pulped testicular material into animals and into his own body. He declared that he had witnessed in these animals and in himself a marked decline in the symptoms of senility, both bodily and mental, with a revival of the extinct sexual potency. As regards man, however, we must

Autosuggestion

not forget that autosuggestion plays a notable part in raising or lowering the level of sexual potency. It seems probable that in some measure Brown-Séquard was self-deceived. Anyhow, his reports on this matter were received with incredulity ; control-experiments made by others gave negative results ; and " rejuvenation " fell into oblivion.

Grafting of Gonads

B.—But surely the oblivion of which you speak has not been lasting ? Recently I read somewhere that Steinach had unquestionably succeeded in rejuvenating rats, and that Harms had had very favourable results in dogs.

Steinach's Experiments on Rats

A.—Man's wish to postpone death and to avert the miseries of old age is too strong to be enduringly stilled. You are right in thinking that some remarkable successes have of late been achieved. The investigators you name opened new paths. They transplanted the testicles of young adult animals into the bodies of senile specimens of the same stock, and these graftings were followed by unmistakable signs of rejuvenation. The slackness and lethargy of old age disappeared ; the animals put on flesh ; a new crop of hair sprouted ; the sebaceous tumours common in elderly animals vanished ; the extinct sexual impulse reawakened ; rut returned ; and the reinvigorated creatures had now a comparatively youthful aspect. After a time, however, the symptoms of rejuvenescence subsided. It cannot be taken as proved that testicular grafts have actually prolonged life.

B.—No doubt the technical difficulties of such operations are considerable. If the ingrafted testicles are to function in their new host, the vas deferens of the graft must be connected up with that of the host, I suppose ?

A.—That is not requisite. The production of spermatozoa in the transplanted testicle, the formation of its external secretion, is not what the operator aims at. He is concerned with the internal secretion, the testicular hormone. It does not matter, therefore, where the graft is inserted. In order to obtain a large surface for the adhesion of the graft, the testicle of the youthful donor is split almost in twain and stitched into the muscular planes of the host (usually among the broad muscles of the abdomen). In successful cases, it quickly heals in, and is invaded by the blood vessels of the host, so that the hormones it secretes find their way into the host's circulation. Steinach has obtained similar results by " vaso-ligature ", by obliterating the lumen of the vas deferens of an ageing impotent rat.

B.—I should have thought that the arrest of the outflow of the testicular secretion would have an injurious effect upon the gland ?

A.—In some measure, that is so. The germinal epithelium, that which produces the spermatozoa (but has usually ceased to do so in senile males), degenerates. However, concomitantly with this atrophy there occurs a proliferation or overgrowth of the cells of the interstitial tissue, those which produce the testicular hormone. The net upshot is an improvement in the general condition. The senile rat, which had grown apathetic, shows a renewed interest in rutting females, and successfully covers them. However, the rejuvenation lasts only for a few weeks. During the last few years, vasoligature has been frequently performed in senile impotent men, with similar results. Potency and sexual desire returned—but it remains open to dispute whether autosuggestion or hormonal influence was the chief cause of the observed changes. In ageing women after the menopause, ovulation and menstruation have recurred after the injection of ovarian extracts, and the women thus treated have looked comparatively young and blooming. But these experiments are still in their infancy, and it is too soon to talk of a trustworthy method of rejuvenation. No more now about hormones. To-morrow we shall consider what support embryology and comparative anatomy contribute to the doctrine of evolution.

NINTH EVENING

METABOLISM OR TISSUE-CHANGE

The Cell

A.—Can you tell me what is the starting-point of an organism, whether it be a worm, a frog, a bird, a mammal, or a human being?

B.—The ovum.

A.—Quite right. But what is an ovum?

B.—Life in the germ.

A.—Your answer is too highly generalised.

B.—A cell.

A.—You are "getting warm", as children say. But now I should like you to tell me what a cell is, and out of what constituents it is made up.

B.—Cells are the bricks of which the organism is built. As to the constituents of the cell, I do not know.

A.—In that case you must bridle a little longer your desire for further proofs of the doctrine of evolution. I cannot discuss embryological details with you until you know at least the elements of cytology (the science of the structure and functions of cells), which is the chief basis of modern biology. The vital manifestations of plants and animals are, in the last analysis, the sum of the processes that go on in the tiny chemical laboratories we call cells.

B.—What does the word signify in this connexion?

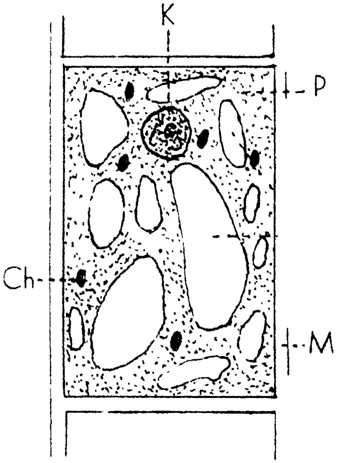

Fig. 29.—A Plant Cell (Diagrammatic).

P, cell-plasm; K, cell-nucleus; Sv, vacuoles; Ch, chlorophyll granules; M, cell-membrane.

An Erroneous Term

A.—In fact the term "cell" is here unhappily chosen, for it relates to an outward detail of appearance, the dead cell-wall, which is not an essential constituent of every cell. (See Fig. 29.) In the biological sense the term was first used by the English scientist Robert Hooke, who, examining a very thin slice or "section" of cork under the best magnification available in those days, was able to recognise that it consists of a number of like elements, to which, owing to the honeycomb structural arrangement, he gave the name of cells. The name was generally adopted for the structural elements of animal no less than vegetable tissues, and was retained though it was soon discovered that partitions between the cells by no means always exist, and that even when present the cell-walls are of trifling importance as contrasted with the cell-contents.

Building Materials of the Organism

As you remarked just now, the cells and their appurtenances (to which the cell-walls belong) are the elementary units, the " bricks ", out of which all the tissues and organs of plants and animals are built up. But cells do not necessarily combine to build up anything; they can lead an isolated and independent life.

Unicellular and Multicellular Organisms

The living world is primarily divided into the two independent stocks of unicellular and multicellular organisms.

The Amœba

All the activities performed by the millions upon millions of cells in our bodies, the taking of nutriment, respiration, digestion—in a word, the whole domain of metabolism or tissue-change—together with locomotion and reproduction, are performed no less purposively by the unicellular amœba, some of the important phases of whose life are shown in the accompanying illustration. (See Fig. 30.)

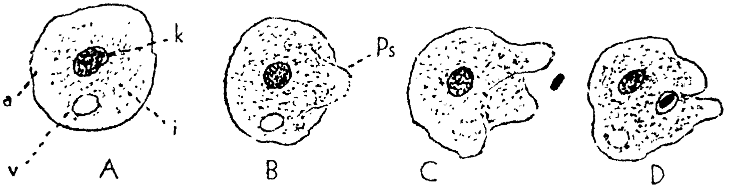

Fig. 30.—An Amœba in four Phases of Movement.

A, resting stage; B, formation of a pseudopodium; C, the amœba is crawling towards a bacterium; D, it has flowed round the bacterium which has been incorporated into the cell-body of the amœba and is seen in a vacuole where it is being digested; *a*, translucent and non-granular peripheral protoplasm; *b*, granular central protoplasm, *k*, nucleus; *v*, contractile vacuole, the simplest form of kidney; Ps, pseudopod.

B.—I think I must ask you for some explanations of the drawing.

A.—Later on. Meanwhile we are concerned with the general characteristics of these organic " bricks ". As previously explained, every cell can be regarded as a little chemical laboratory, within which go on all those processes whose aggregate makes up what we term life.

All Life is associated with Cells

Whenever and wherever we encounter life, it is associated with a cell or with a multiplicity of cells, that is to say with an elementary organism whose body consists of two different

Cell-Body and Cell-Nucleus

substances, the cell-body (or protoplasm) and the nucleus. Nucleus and protoplasm are the essential constituents of every cell. (See Fig. 31.) Life cannot go on without their collaboration. For just

Division of Labour

as in the body of all the higher organisms there is a division of labour among the various organs and tissues, so is there within the cells, especially in those cells which are complete organisms, for in these there is often a far-reaching differentiation of the cell-body, resulting in the formation of definite cell-organs. We find a mouth and a sort of gullet, for the better intake of nutriment; cilia, for locomotion or for making water-currents that carry the prey into the mouth; various kinds of cell-membrane, for the protection of the cell-body; a contractile vacuole, which is the simplest form of kidney, for the excretion of residues and the products of disintegrative or katabolic change; and various other structures. Indeed, the organisation of many of these unicellular animals, or protozoa as they are called, is so complicated that we seem to have before us a higher organism with differentiated organs. Still, the fundamental elements of the cell are the cell-body and the nucleus.

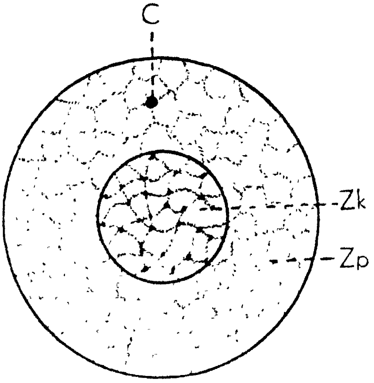

Fig. 31.—Diagram of a Cell.

Zp, cell-plasma or cytoplasm, Zk, nucleus C, centrosome.

Precursors of Cells

B.—But if the theory of spontaneous generation be sound, there must exist or have existed simpler organisms than these cells.

A.—I agree. It is now generally believed by biologists that the protozoa, no less than ourselves, had a long series of ancestors; but we only infer the existence of these primitive forefathers, having no direct knowledge of them. In many cells formerly believed to be non-nucleated, improvements in microscopes and in staining technique have demonstrated the presence of nuclei, or of nuclear substance disseminated in various parts of the cell-body. Other cells, such as the red blood-corpuscles of human beings and other mammals, though non-nucleated when adult, develop out of nucleated cells.

Size of Cells

B.—How large are cells?

A.—Their size is very variable. Most of them are extremely small, near to or below the limit of naked-eye visibility. The amœba is just visible without a lens. But many cells are so incredibly small that they only become visible when magnified two or three thousand times. Among the smallest are many bacteria, a few of the protozoa, and the spermatozoa of most animals.

B.—I still find myself at a loss when I try to imagine their actual size.

A.—Many of the protozoa and bacteria measure only 1/3000th of a millimetre in their largest dimension; and the pyogenic cocci are much smaller still, their cubic content being no more than 1/700,000,000th of a cubic millimetre.

B.—That is inconceivably small.

A.—Think of a drop of water. It could easily find room for several milliards of micro-organisms; and a tumbler of water would, comparatively, offer them more space than the whole world does to human beings. In other words, it would take more than six billions of pyogenic cocci to weigh a gramme; or, to put it in another way, one such coccus weighs about 1/600,000,000th of a milligramme. The exciting agents of bovine tuberculosis are so small that they constitute what is called a filter-passing virus, i.e. they traverse the pores of unglazed porcelain out of which a Chamberland filter is made. The exciting causes of measles and scarlatina have never been discovered, presumably because they are below the limits of visibility.

WEIGHT OF A PYOGENIC COCCUS

B.—How is it possible to take effective measures for the prevention of a disease when its exciting causes are unknown?

A.—Fortunately there are ways and means. I told you that intestinal parasites are only enabled to survive in the intestine because their skins excrete a counter-poison, an antitoxin, which protects them from the digestive juices of their host. The power of forming antitoxins is one of the organism's most important defensive measures against all the disease-producing agents and other noxious substances that make their way into the body. In general, a healthy organism produces more of these defensive substances than is needed for safeguarding against the causes of the infective diseases. It is upon that that the practice of protective inoculation depends. The excess of antitoxin can be stored up for future use, or can be utilised by injection into another organism which has been exposed to the exciting causes of the disease. We find that in those who have suffered from various contagious diseases, such as measles, scarlatina, or smallpox, a natural immunity (" natural ", because not brought about by medical intervention, though it is really an acquired immunity) to the disease lasts a long time—often for decades or throughout life. A person who has had measles can hobnob with measles patients without

TOXINS AND ANTITOXINS

PROTECTIVE INOCULATION

NATURAL IMMUNITY

taking the illness, for as a rule his blood is sufficiently charged with measles antitoxin to save him from infection with that disease.

Campaign against Measles

Degkwitz has taken advantage of this fact to protect children already infected, from an actual outbreak of the disease. In the majority of such diseases there is a " period of incubation " between the date of infection and the actual onset of morbid symptoms—a period ranging from a few hours or days in some diseases, to several weeks in others. The blood of children that have just recovered from measles is peculiarly rich in measles antitoxin, and Degkwitz injected blood-serum from such convalescents into those who were sickening for measles. Thus we can successfully prevent a disease even though its exciting cause remains undiscovered. Unfortunately there is no " general antitoxin ". The effects of each antitoxin are specifically protective against the disease to cope with which an infected organism has produced it. Habituation to a particular virus protects against this virus only. We shall have by and by to consider more closely these internal protective forces of the organism.

Number of the Cells

B.—How many cells are there in a multicellular organism ?

A.—You might as well ask, " How many pounds must one pay for a landed estate ? " The number of cells varies enormously from one kind of animal to another. Naturally, there are many fewer cells in the body of an earthworm than in that of a horse. Indeed, it is impossible to count the cells of a higher animal. One can only make a rough guess. In man we reach figures running to several billions. Besides, in the living body, cells are incessantly dying and

Death and Renewal of Cells

being replaced. For instance, the tiny scales which are continually falling from your skin, are dead and cornified cells. In many of the lower multicellular animals the number of cells is so small that an approximate count can be made, and we have learned that their number is fairly constant from individual to individual of the

Numbering the Cells of a Rotifer

same species. For instance, Martini has made a count of the cells of various specimens of the rotifer Epiphanes senta. The rotifers, which are among the smallest of the multicellular animals (metazoa) and are by laymen often confused with the infusoria (one kind of the unicellular animals or protozoa), have a very simple structure. According to the prevailing view, they were the ancestors of the worms. Their bodies are so transparent that it is easy to count the number of the cells. Martini found that in epiphanes the muscular system consists of 86, and the nervous system of 264 cells. The total number of cells in the body is round about 960 cells. In the higher animals, such enumerations are only possible in the case of particular organs. Here likewise the number of cells is found to be approximately constant in any one species. The lens of the vertebrate eye, for example, consists of radially disposed lamellæ, and each of these lamellæ is made up of a definite number of elongated cells arranged in series. In the newt, the number of the lamellæ ranges from 114 to 128; in the pig, from 2503 to 2722; and in the cat, from 3411 to 3623.

SIZE AND SHAPE OF CELLS

B.—What about the size and shape of different kinds of cells? Are these approximately constant for each kind?

A.—I cannot answer your question with a simple Yes or No, for the cells of the various organic systems differ in this respect. For many cells, however, the answer is in the affirmative. Thus in the

RED BLOOD-CORPUSCLES

animals of any species we find a striking uniformity in the shape and size of the red blood-corpuscles and the male reproductive cells, respectively. A trained eye can instantly recognise under the microscope the source of a particular specimen of blood or semen.

B.—How large are human red blood-corpuscles?

A.—As a preliminary to answering that question I must introduce you to a new standard of measurement, devised to avoid having to use fractions with preposterously large denominators. In microscopy we reckon, not by centimetres and millimetres, but by what is called a micro-millimetre or micron, which is a thousandth of a millimetre, and is usually denoted, for short, by the Greek letter μ (pronounced "mu"). In camels and a few allied species, the red blood-corpuscles are oval, but in all other mammals they are circular biconcave discs, i.e. like biscuits whose sides have been slightly hollowed. Their average diameter is: in man, $7{\cdot}7\,\mu$; in the rabbit, $6{\cdot}9\,\mu$; in the sheep, $5\,\mu$; and in the goat $3{\cdot}5\,\mu$. Giants among the red blood-corpuscles are found in the lower amphibia and in fishes of the shark order. For instance, the oval corpuscles of the cave-olm (Proteus anguinus) are $58\,\mu$ long and $34\,\mu$ wide.

B.—Now I must ask you something which you may think I ought to know. What is the function of the red blood-corpuscles, and why are they red?

FUNCTION OF THE RED BLOOD-CORPUSCLES

A.—Their colour and their function are intimately connected. The red blood-corpuscles contain a ferruginous albumin, called hæmoglobin, which has the power of absorbing and retaining oxygen from the inspired air. It then becomes oxyhæmoglobin, which gives arterial blood its bright-red colour. From the lungs the

CIRCULATION OF THE BLOOD

oxygenated blood makes its way through the left auricle of the heart into the left ventricle. Expelled by the contraction of this chamber into the aorta, it passes through the continually subdividing arteries into the fine ramifications that are called capillaries whose spongy network invades almost every organ. On their way through the capillaries, the corpuscles surrender to the tissues the oxygen they have been carrying, and absorb in return the carbonic acid produced by combustion—for the living body is a slow fire, much less "slow" in warm-blooded animals than in cold-blooded animals and in plants. The blood thereupon assumes the dark bluish-red colour of venous blood. Passing back to the heart through the veins, the blood traverses the right auricle and the right ventricle, being pumped by the latter into the "lesser" or pulmonary circulation. The lungs consist of a sponge of air-cells (do not confuse the cells or alveoli or chambers of the lung with the cells to which this evening's talk is largely devoted), whose walls contain a rich network of capillaries. Here the blood discharges its carbonic acid and takes a new store of oxygen into its corpuscles. Such is the nature of the process known as the circulation of the blood. The work done by the two sides of the heart at each beat amounts to round about 69 gramme-metres. With a pulse-rate of 70, this signifies 5·72 kilogramme-metres per minute, and 8236 kilogramme-metres per day of twenty-four hours. In case you don't know what a kilogramme-metre is, I may explain that the work done by the heart in twenty-four hours would suffice to lift 8236 kilogrammes (more than 8 tons) through a height of one metre. The heart continues this work untiringly through all the days of our allotted span—until at last it fails.

Work done by the Heart

Number of Red Blood-Corpuscles

B.—Since the size of the red blood-corpuscles differs so much in different species of animals, I suppose the number differs likewise?

A.—Of course. Speaking generally, the number is inversely proportional to the size. The smaller the diameter, the larger the number; and conversely. In the cave-olm, whose oval corpuscles are comparatively enormous, a cubic millimetre of blood contains 360,000; but in man the same quantity of blood contains on an average 5,000,000. The number varies with age, sex, and climatic conditions. A woman's blood contains, as a rule, about half a million fewer corpuscles per cubic millimetre than a man's. Prolonged residence at great altitudes, where the air is rarefied and therefore contains less oxygen in a given weight or volume, induces an increase in the corpuscular richness of the blood, so that the body's need for oxygen can be satisfied.

Influence of Altitude

B.—How many red blood-corpuscles in all are there in the human body?

A.—Since the blood comprises about one thirteenth of the body-weight, a man weighing 80 kilogrammes will have about 6 litres of blood, and therefore approximately 30 billions of red blood-corpuscles.

DURATION OF LIFE IN RED BLOOD-CORPUSCLES

The average duration of life of a red blood-corpuscle being about five weeks, this signifies that in a man who lives to be seventy about 13,000 billions of corpuscles must be produced.

B.—Why do mammals need so many more red blood-corpuscles than the olm does ?

DEPENDENCE OF THEIR NUMBER UPON THE ACTIVITY OF TISSUE-CHANGE

A.—I have already given you a hint of this when I spoke of warm-blooded animals as slow-combustion stoves, but much less slow than cold-blooded ones. This leads us a little aside ; but it really does not matter whether we discuss the subject now or later. When you want your slow-combustion stove to burn faster, you open an air-intake. Warm-blooded animals have a larger number of red corpuscles because in them tissue-change is more active, so the draught in the fire must be fiercer. They need more oxygen.

B.—But what bearing has that upon the number of the corpuscles ? Can it make any difference whether 20 large or 40 small corpuscles take up the oxygen from the air ?

THE PRINCIPLE OF INCREASE OF SURFACE

A.—Come back to the comparison with a coal fire. When you want it to burn more fiercely, you break up the coal. For the hæmoglobin to do its work effectively, it must come in contact with the oxygen it is to take up, and must do this over as large a surface as possible. If you distribute the substance of one big ball into a number of little ones, the amount of surface exposed is considerably increased. Numerous small corpuscles have much more surface than a few big ones having the same aggregate mass, and with the same amount of hæmoglobin you can in this way get much more contact between hæmoglobin and the atmosphere. This simple mathematical principle comes into operation wherever, in the organism, there is need for more active, more thorough, absorption. To show you how, while preserving the same ground-plan, evolution works by a gradual advance from the simple to the complex, and how increased vital demands bring about an intensification of function, we will consider some other examples—for the theory of evolution gives a logical and consistent explanation of what has taken place in all such cases.

INCREASE OF SURFACE IN THE INTESTINE

B.—I suppose it is the same when heat has to be dispersed as when it has to be absorbed ? In a central-heating apparatus, or in the radiator of an automobile, the principle of increase in surface with reduction in the size of the elements is manifest.

A.—Quite so. Now consider in this connexion the development of the alimentary system, in which the inner surface of the intestine plays a similar role for the absorption of the dissolved nutritive substances as is played by the outer surface of the red blood-corpuscles

THE FRESH-WATER POLYP

in the absorption of oxygen. In the common fresh-water polyps, Hydra viridis and Hydra fusca, the tubular body consists of only two layers of cells. The mouth, ringed by tentacles, leads into a blind sac, which functions at one and the same time as stomach, intestine, and body-cavity. The development of this animal has been, as it were, arrested at the gastrula stage, "gastrula" being the name given to a two-cell-layered embryological phase through which, as you will subsequently hear, all the higher animals pass in their early development. The hydra has no separate anus. The mouth serves both for the ingestion of food and for the discharge of indigestible residues. Such a smooth-walled intestine with its scanty surface can only digest "in the rough" so to say. The food that has been swallowed is coarsely subdivided, and, in this inadequate state of preparation, it is then taken in gobbets into the cells lining the wall

INTRA-CELLULAR AND EXTRA-CELLULAR DIGESTION

of the tube. In these animals, then, an intra-cellular digestion akin to that which occurs in the amœba still persists. In higher animals, on the other hand, the fundamental process of digestion, the reduction of the solid food-materials to a liquid state, is effected in the intestinal canal, still in a sense outside the body or at any rate outside its cells. Only in the fluid form does nutriment enter the intestinal cells, pass through them into the lymph and the blood, thereafter to be distributed all over the body. But for this thoroughgoing preliminary liquefaction and for ease of absorption, there must be a great increase in the digestive and absorptive surfaces of the alimentary canal. In addition, an apparatus must come into being whereby the digestive juices elaborated in special groups of cells

DIGESTIVE GLANDS

can be poured into the digestive canal. This leads to the formation of the digestive glands and their excretory ducts. In earthworms the intestinal canal is still nothing more than a long, straight tube, running the whole length of the body and opening on the ventral side close to the posterior end. As organisation becomes more complicated, the intestine grows till it is longer than the body, and then it has to be coiled up. Furthermore, the digestive part becomes marked off into sections adapted for different phases of the digestive process. Into these respective sections open the excretory ducts of various glands or groups of glands; those of the salivary glands, into the mouth; those of the pancreas and liver, into the duodenum; etc. By stages the food is disintegrated and liquefied, being gradually prepared for absorption through the wall of the intestine. But a simple elongation of the alimentary canal did not suffice; the inner surface of the intestine likewise needed enlargement. This can be

INTESTINE OF SHARKS

effected in various ways. In sharks, the intestinal mucous membrane forms an elongated spiral fold, which runs like a winding staircase along the interior of the gut. In the higher vertebrata the same object of increasing surface is achieved by

Formation of Villi

the projection of villi as they are called, tiny finger-shaped processes, from all directions into the lumen of the tube, so that the inner surface has a shaggy aspect. You will see the same principle of increase of surface at work in the phylogeny of the lungs, the respiratory organs of air-breathing vertebrates. But the account I have given of the alimentary canal should already have sufficed to make the principle clear to you.

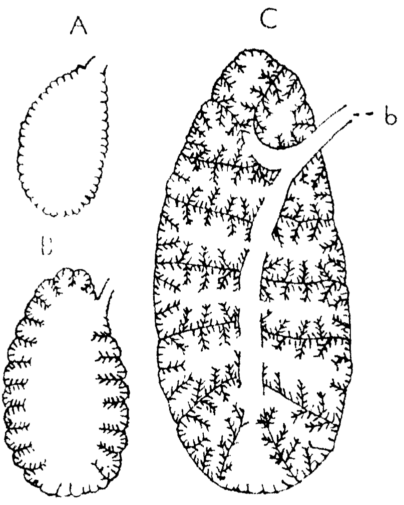

Fig. 32.—Diagram to show the Increase in Inner Surface that is effected during the Phylogeny of the Lung.
b, bronchus.

B.—I should have been glad to learn further details of the digestive process, and what parts the respective sections of the alimentary tract play in it. (See Figs. 32 and 33.)

Nutrition in Plants and Animals

A.—As I think you must know, there are basic differences between the nutrition of plants and animals. Whereas plants, absorbing gases and solutions of inorganic salts, can out of these simple materials build up organic compounds, no animal can perform such synthetic processes. All animals, vegetarian feeders no less than the carnivora, are dependent for food upon organic compounds, which must be split up and elaborated by the digestive juices of the gastro-intestinal canal.

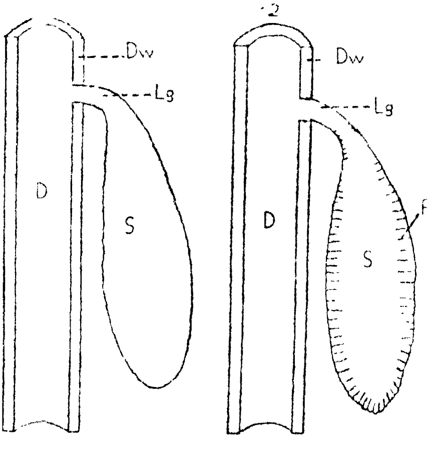

Fig. 33.—Development of the Swimming-bladder.

1, smooth-walled, in a bony fish ; 2, in a lung-fish, where the lining mucous membrane has become plicated in order to increase the surface, so that the transformation into a lung has begun. D, alimentary canal ; Dw, wall thereof ; Lg, air passage (ductus pneumaticus) ; S, swimming-bladder ; F, folds.

Effects of the Digestive Juices

B.—What do you mean here by " splitting-up " ?

A.—The organic compounds (carbon compounds which have an extremely complex chemical structure) taken into the body as food are, with the aid of the secretions of the glands in the wall of the stomach and of those which open through ducts into the intestine, decomposed into simpler compounds, one " brick " or " radical " (the latter is the scientific term) after another being split off, the process being generally accompanied by the taking-up of water by the dissociated radicals.

B.—You'll have to give me concrete examples, please, to make the matter clear. I know that man needs, as the elements of a complete diet, carbohydrates, fats, and albumins. What, precisely, happens to all these ?

Chemical Structure of Protoplasm

A.—Before I can answer that, I must give you a general idea of the composition of protoplasm, the enigmatic substance with which all vital manifestations are associated. It is an extremely unstable aggregate of various carbohydrates and albumins or proteids (the latter contain nitrogen). No doubt it is built up of the same chemical elements as inorganic compounds, but it is far more intricate in composition than any of these. Protoplasm always contains carbon, hydrogen, oxygen, nitrogen, and sulphur, as well as numerous salts.

Indispensability of Albumins to Protoplasm

Albumins are essential to it, and you ought, therefore, to have mentioned them first in your enumeration of food-stuffs. Some of the protozoa can utilise no other. We human beings cannot get on without fats and carbohydrates, but these do not suffice to replace the bodily substance that is consumed during our vital processes, for they contain no nitrogen, a fundamental ingredient of protoplasm. On the other hand, the animal body can manufacture fats and carbohydrates out of albumin, thus producing from it all the elements of a complete diet.

Structural and Functional Tissue-Change

Albumin is the primary necessity in the way of food-stuffs for an animal, and in the long run nothing else can take its place, whether in youth for the purposes of growth, or throughout life in order to make good the unceasing waste of tissue. Still, though animals can live on a purely albuminous diet, fats and carbohydrates are important to their vital processes, since they contribute to the production of muscular power and body-heat, thus maintaining what may be called " functional " as contrasted with " structural " metabolism—that functional metabolism which would otherwise have to be maintained by the more costly albumins, or, if these were lacking from the diet, by the albumins already present in the tissues. Carbohydrates and fats are, therefore, in a sense, substitute elements of nutrition. They can be stored up in the body for

Hibernation

use in time of need. Thus, abundant quantities of fat are stored up by all animals that go to sleep during the winter months.

Nourished by their own Fat

Hibernating animals consume no food, but are nourished by their own fat. In resting muscles, again, the carbohydrate glycogen is stored, to be gradually consumed as a combustible source of energy during periods of activity. I have already told you that the organic compounds ingested as food must, before they can be turned to useful account, be split up into simpler compounds and fluidised.

Enzymes or Ferments

This work is done with the aid of substances called enzymes or ferments which are formed in the cells of the alimentary tract and its associated glands, and discharged into it in the secretions. We know very little about the real nature of these enzymes. Willstädter believes that an enzyme consists of a colloidal " carrier " and of a group of chemical radicals associated with this carrier. The specific working of the enzyme depends upon the chemical affinity between the group of radicals and some particular substance. To use Emil Fischer's simile, just as a key fits a lock, so an enzyme is specialised to split up a particular chemical substance and has no effect upon others. A minute quantity of an enzyme is able to decompose an almost unlimited quantity of the appropriate food-stuff. Presumably a loose chemical combination takes place between the enzyme and the food-stuff ; speedily followed by dissociation in which the decomposition and hydration of the food-stuff are effected, while the enzyme is left as it was, ready to repeat its work upon more of the food-stuff. Thus the process goes on unremittingly, without exhaustion of the ferment.

Catalysers

B.—It seems to me that these enzymes or ferments act just as spongy platinum acts in promoting the combination of sulphur dioxide with oxygen to form sulphur trioxide. They function as catalysers, substances which initiate, favour, or accelerate a chemical process by their mere presence, without themselves undergoing any modification.

A.—Yes, the action of enzymes or organic (not organismal) ferments has often been compared with that of catalysers.

Specific Action of Enzymes

Since the action of enzymes is specific, of course the organism must produce a number of them to deal with the various food-stuffs ingested. To give you a few examples : the diastases transform starch and the cellulases cellulose into sugar ; the lipases split fats into fatty acids and glycerine ; and the amidases or proteases disintegrate albumins into peptones and amido-acids, which are then absorbed by the cells of the intestinal wall and rebuilt into the substance of the body.

In this reconstitution of the more complex organic compounds, enzymes likewise play a part. The processes of digestion can also

ARTIFICIAL DIGESTION

be studied outside the body, in a test-tube, where the working of enzymes can be substituted by heat and mineral acids. Thereby such processes are deprived of much of their obscurity, and it is no longer necessary to call for help in explanation to a supposititious but mysterious vital force.

B.—All the same, it seems to me that everywhere we are faced with enigmas.

A.—Congratulate yourself that you can still wonder. Most people have grown so dull-witted that they have lost this faculty. Only when some inexplicable process comes under their observation for the first time, do they open mouth and eyes in astonishment; after that, they take it all as a matter of course. Actually, environing nature is but one stupendous wonder, which should inspire reverence. It seems to us self-evident that a stone should fall to earth. We "explain" it by "the force of gravity", and should be greatly surprised if, on releasing a stone from the hand, we were to see it fly upward. But that would be no more inexplicable than the other, since we do not know what gravity is. Gravity is not an explanation, only a description.—Is your thirst for knowledge quenched?

B.—You said you were going to tell me about the specific functions of the various segments of the alimentary canal in the higher animals.

THE STOMACH IN RUMINANTS

A.—Well, let us consider, as example, the stomach of a cow or other ruminant; for in these animals specialisation of the alimentary tract has gone very far, so that even the stomach, whose main function in most mammals is to effect a preliminary disintegration and partial solution of the food, has become subdivided into several parts. The grass a cow bites off when grazing is, to begin with, superficially masticated and insalivated (mixed with saliva). Thus prepared, it is swallowed, passing into the largest segment of the stomach, the "first stomach", farding-bag, or rumen. Now please give me your very careful attention. You know how much talk there is of the struggle for life, as if war to the knife were unceasing and universal, as if existence were a perpetual dog-fight. In the nature of things it is inevitable that plants should serve animals for food, and that the vegetarian feeders should themselves be preyed upon by carnivora; but side by side and interwoven with this struggle and warfare, much peaceful life and even a life of mutual aid continues, partners of different species drawing advantage each from the other.

SYMBIOSIS

In these cases we no longer speak of parasitism, but of a life-community or symbiosis. Such a peaceful symbiosis goes on in the farding-bag of ruminants. The digestive juices secreted by that organ are not capable of dissolving cellulose, the solution being effected by certain bacteria which have taken up their habitat in this sheltered place, where they also find food and warmth. When the digestion of cellulose has gone on for a time in the rumen, and the grass has been sufficiently softened, the pulped material is passed on into the "honeycomb" or reticulum, the second division of the stomach. When the cow feels that her farding-bag and honeycomb are sufficiently full, she lies down and begins to "ruminate". The food is regurgitated from the second stomach into the mouth, where, as the "cud", it is rechewed, worked about with the tongue, and once more insalivated. Thereupon the mass of food, whose digestion is now well advanced, is swallowed once more; not, however, into the rumen, but through another gullet into the third stomach, the manyplies, omasum, or psalterium, and thence it passes into the fourth stomach, the rennet-bag or obomasus. Only the manyplies and the rennet-bag are homologous with the human stomach; the rumen and the reticulum are formed as diverticula from the œsophagus.

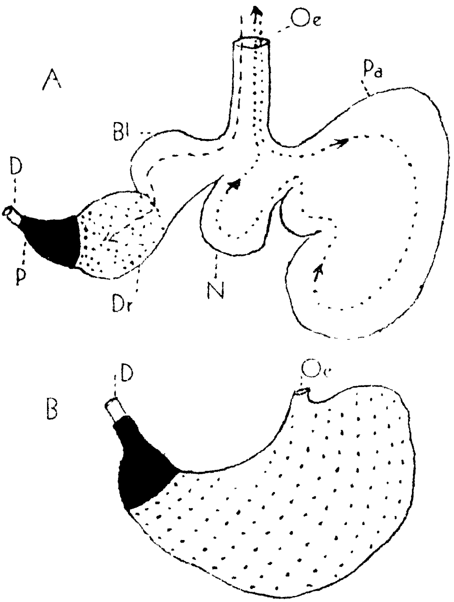

FIG. 34.—COMPARISON OF RUMINANT AND HUMAN STOMACH.

A, the stomach of a ruminant; B, the human stomach; Oe, gullet or œsophagus; Pa, rumen; N, reticulum; Bl, omasum; Dr, obomasus; P, pyloric portion; D, small intestine. The dotted line and the arrows show the course of the food before rumination; the interrupted line with arrow, its course after rumination.

B.—Comparable, then, to the pigeon's gizzard?

FERMENTATIVE DIGESTION

A.—You hit the nail on the head. In the third and fourth stomachs of the ruminant there go on processes analogous to those which take place in the human stomach, for here enzymes or ferments get to work. After the food has been thoroughly liquefied in the rennet-bag, it passes into the longest segment of the alimentary canal, the small intestine, where the digestive juices poured into it carry on the disintegrative processes to a stage at which absorption of the dissolved nutritive substances can begin. The last section of the alimentary canal, the large intestine, serves mainly for the temporary storage of indigestible residues, which, after a time, are expelled as fæces.

B.—How long is the alimentary canal in various animals?

EFFECTS OF NUTRIMENT ON THE INTESTINE

A.—The length of the alimentary canal depends upon the kind of food an animal habitually consumes. Since the splitting-up of vegetable nutriment imposes greater demands than a flesh diet does upon the digestive activities, the intestine of vegetable feeders is longer in proportion to the body-length than is that of carnivora. There are many exceptions, inasmuch as digestive capacity is not exclusively determined by the length of the canal. As you already know, an enlargement of the absorptive surface can be secured by an expansion of the lumen of the tube and by a more abundant formation of villi. In our domesticated cattle, the length of large and small intestine taken together averages 60 yards, being about 30 times the body-length. In human beings, who are omnivorous, the gut averages 26 feet in length, being nearly 5 times the stature (head body, and legs together—not strictly comparable with the body-length of a quadruped). In the cat, a carnivore, the gut is about four times as long as the body.

B.—If the food usually taken has such an effect, one would suppose that the length of the bowel might increase or diminish as the diet varies.

DOMESTICATED AND WILD CATS

A.—Such is, in fact, the case, as we may learn from a comparison between our tame cats (habituated for generations to a mixed diet) and their wild congeners. Daubenton, who studied the subject, found the intestine of the tame cat to be not only more spacious than, but also about a third as long again as, that of the wild cat. Still more strikingly is the influence of nutriment upon the length of the intestine shown by an examination of tadpoles and frogs. Tadpoles are strict vegetarians, and in them the intestine is seven times as long as the body ; when they grow up into frogs they become carnivorous, and then the gut is only four and a half times the body-length.

TADPOLES

DISTRIBUTION OF NUTRITIVE ELEMENTS BY THE BLOOD-STREAM

B.—If I have understood you aright, the fluid nutritive elements taken up by the intestinal cells are passed on into the blood. The circulation then distributes them throughout the body, supplying the needs of all the cells and tissues.

A.—That is so.

B.—The blood, then, must be equably satisfied with the various nutritive elements. But I presume the nutritive needs of the various kinds of cells in the body must differ greatly, since these cells diverge so much one from another in form, structure, and functions ? A brain-cell, for instance, cannot need the same nutritive elements as a connective-tissue cell or a muscle-cell ; nor these the same as a reproductive cell, a splenic cell, or a cell in the bone-marrow ?

A.—Yes, you are right. But what are you driving at ?

B.—I want to know how the various kinds of cell pick out of the blood the precise nutritive elements they require.

SEMI-PERMEABLE MEMBRANES

A.—The cell-membranes that envelop the cell-bodies are semi-permeable membranes, whose permeability for different materials varies from case to case. This endows the cells with a capacity

AUTOMATIC SELECTION OF MATERIALS

for what may be termed the automatic selection of materials from the " mixed diet " presented to them by the blood. Every cell thus picks out only the materials appropriate to itself. Whereas water can pass freely through any cell-membrane, a cell-membrane will give passage only to certain salts, and will bar the way to others.

OSMOSIS

In this transference of materials, osmosis plays an important part.

B.—What is osmosis ?

A.—The endeavour of two fluids one of which is a stronger solution than the other, or one of which is a salt-containing fluid and the other the same solvent but not containing any of the salt in solution, when separated from one another by a porous partition, to equalise their respective concentrations by diffusion through the pores. If the separating membrane is equally permeable by the pure fluid and by the fluid containing salt in solution, there is a flow both ways. Confining ourselves to solutions in water (with which we are mainly concerned in animal and vegetable physiology), I may say that the stronger solution sucks water through the membrane out of the weaker solution, or sucks pure water, if that is what is present on the other side of the membrane, and the concentrate passes through in the reverse direction, until equilibrium is established between the two sides. If, on the other hand, we have to do with a semi-permeable membrane, which only allows the pure fluid to pass through it, water makes its way in one direction into the vessel containing the salt solution, to produce there a definite

OSMOTIC PRESSURE

and measurable osmotic pressure, as it is called, proportional to the molecular weight of the salt in solution.

B.—An example would render what you are saying more comprehensible.

A.—The best thing will be for you to make an experiment. Go to the butcher's and buy a pig's bladder, fill it three-quarters full with a concentrated solution of common salt, and tie the neck firmly. Then hang the bladder immersed in a bucket of pure water. You will see that it gradually undergoes distension, and the pressure inside it may become so great as to burst it. Especially in the physiology of plants this osmotic pressure plays an important part. Their cell-membranes are semi-permeable, and their protoplasm contains mineral salts in solution, so, when water is available, they suck it in, and the plant becomes tensed. But they are continually giving off water through the stomata (mouths, little apertures in their leaves), and if water to replace this be not forthcoming, they wilt and droop.

B.—Does such an osmotic pressure arise in the animal body?

Osmotic Pressure in our Vascular System

A.—Yes, in our arteries, for instance; and since the percentage of mineral salts in the blood is fairly constant, the osmotic pressure in the bloodvessels of the higher animals remains round about seven atmospheres.

Permeability of the Cell-Membrane

B.—Upon what chemical or physical qualities does the varying permeability of the cell-membranes to this or that substance depend?

A.—In this matter many puzzles remain to be solved, but we know a good deal that throws light on them. Certain stains or dyes can

Staining Live Cells

make their way into living cells. Since the various constituents of the cell have varying affinities for such dyes—methylene blue, for instance—it is possible to stain living cells and to make the different parts stand out on the microscopic field. It has been shown that

Effect of Lipoids

such stains are dissolved by lipoids, fat-like substances present in protoplasm, and that it is in virtue of this solubility that they are able to pass through the cell-membrane. It is assumed that cell-membranes consist mainly of lipoids, which dissolve the stains, and then pass them on to the interior of the cell. If a living cell thus stained (an amœba, let us suppose) be removed from the staining solution into clear water, the reverse process sets in. The dye-stuff gradually passes out of the cell into the surrounding water. It is

Alcohol and the Brain

in the same way that alcohol we have drunk passes into our cells from the circulating blood. Since the ganglion cells of the cerebro-spinal nervous system are especially rich in lecithin, which is akin to the lipoids, they are prone to absorb the alcohol, with the production of the symptoms of mental and bodily disco-ordination known as alcoholic intoxication. But these processes are far from explaining all the processes of the exchange of materials between the cells and the fluids in which they are immersed. Many substances are obviously exceptions to the laws of the spontaneous equable intermixture of two or more fluids brought into juxtaposition (laws of diffusing), so that one must suppose the cells to intervene actively

Independent Activity of the Cells

like an experimenter in the laboratory, promoting the movement of this substance in one direction and of that in another. But amid

THE RED BLOOD-CORPUSCLES ONCE MORE

these digressions we have forgotten our red blood-corpuscles. In these, a numerical increase accompanied by a reduction in size likewise results in an enormous expansion of their absorbing surface, with the result that in a given time the same amount of hæmoglobin can take up much more oxygen. Since the surface of a human red blood-corpuscle measures 127 square micro-millimetres, the thirty billion corpuscles of an adult human being must have a total area of nearly 3000 square metres—approximately three-quarters of an acre, a space big enough for a house with a fine garden.

B.—How little one knows of one's own body!

A.—You obtain a like surprisingly large superficies if you calculate the inner surface of the pulmonary alveoli, the tiny chambers in the lung where the blood-corpuscles come into contact with the inspired air.—Any more questions?

B.—Yes. I should like to know whether the difference in size between two animals of the same species depends upon a difference in size of the cells in one and the other, or upon one of them having more cells.

GROWTH IN SIZE THROUGH THE MULTIPLICATION OF CELLS

A.—Here, once more, a straightforward answer is impossible, since both factors are at work. Generally speaking, in different members of the same species, the cells of any particular tissue or organ have much the same size and shape. With a few reservations it may be said that the growth of the body is determined, not by an increase in the size of the cells, but by an increase in their number. Strassburger was able to prove that in the case of plants an increase in size is the outcome of a numerical increase in the cells. Bovery came

GIANT AND DWARF

to the same conclusion as regards men from a study of Machnow, the giant, whose stature was 7 ft. 10 in., and Smaun Sing Hpoo, the dwarf, whose stature was 2 ft. 10 in. Epithelial cells scaled from the tongue of the giant and from that of the dwarf were of the same size as those of normal human beings. Rabel obtained identical results when examining the liver-cells and the kidney-cells of dogs of different breeds. The difference in size between the liver or the kidney of a St. Bernard and that of a Chinese sleeve-dog depends on a difference in the number of cells. On the other hand, Weiss found that in fishes growth, and the varying size of different individuals of the same species, were mainly determined by whether the muscle-cells were large or small.

B.—The results seem contradictory.

A.—That is so. The organs vary in this respect. There are cells whose size is typical for a particular species, remaining of the same dimensions in giants and in dwarfs. Besides the red blood-corpuscles and the spermatozoa, the connective-tissue cells, the gland-cells, and the epithelial cells of the skin and the mucous membranes come within this category. On the other hand, the size of muscle-cells, ganglion cells, and the cells of the organs of special sense seems to vary with the size of the animal's body. In this connexion, I should like to refer to a matter that will come up for fuller consideration later. Thanks to the appearance of what are called sports, mutations, or sudden variations, animals or plants occasionally produce offspring which differ markedly from customary members of the species and transmit these peculiarities to their offspring. In an

The Giant Evening Primrose

experimental field where de Vries had planted the evening primrose (Œnothera Lamarckiana), a specimen appeared with a stronger stalk, a taller growth, and much larger flowers than the parent plant, so it was given the name of the giant evening primrose (Œonthera gigas). Microscopical examination showed that the enlargement of the plant was not due to an increase in the number of the cells, but to an increase in the size of the cells to about double the normal.

Cell-Death through the Division of Labour

B.—You said a while back that the duration of a red blood-corpuscle's life was only about five weeks. Are all the cells of our body as short-lived, and what leads to their death?

A.—I will answer your second question first. In multicellular organisms, the speedy death of many of the cells is due to the far-reaching division of labour which has taken place. The consequent extreme specialisation of the cells deprives them of their capacity for subdivision, upon which the potential immortality of cells depends. Whereas unicellular organisms, the protozoa, have to carry on all the vital functions, and propagate by subdivision, the cells in the cell-community of a higher organism renounce this universal competence, ceasing to be jacks-of-all-trades. They become specialists, with a restricted function, and can often do but one kind of service to the community. Not infrequently they forfeit even their characteristics as cells, and only fulfil their function when they are dead or dying.

B.—You have taken me completely out of my depth.

Our Epidermis

A.—Think of our tough scarf-skin or epidermis, which protects the delicate tissues underneath from injury. (See Fig. 35.) What does it consist of?

B.—Horn.

A.—Yes, you are right, but this horny substance is made up of a vast number of cornified epidermic cells, which are no longer alive,

Perpetual Replacement of the Scarf-Skin

and which, as they are cast off, are continually replaced by other, moribund cells. In like manner, two of the most important constituents of a living tree, the bark and the wood, consist mainly of dead cellular material. As for our red blood-corpuscles, they have lost their title to be considered entire and fully valid cells, just as a gelding is not an entire and fully valid horse, for they no longer possess a cell's most essential organ, its nucleus.

RECRUITS TO FILL THE THINNED RANKS

That is why they have so brief a career. But their speedy decline matters nothing to the organism as a whole. As the ranks are thinned, new recruits are continually stepping forward to fill the places of their lost comrades, these new cells being formed in the walls of the capillaries of the spleen, the liver, and the marrow of the long bones.

CONCERN, NOT FOR THE INDIVIDUAL, BUT FOR THE SPECIES

A squandering of individuals is characteristic of organic nature, whose concern is for the perpetuation of the species. Through the division of labour, the body-cells have lost the faculty of reproducing a complete organism ; they can merely reproduce as specialists, an epidermic cell dividing to become a pair of epidermic cells, and a connective-tissue cell dividing to become a pair of connective-tissue cells. Only the reproductive cells retain the power of generalised reproduction, and are, in a sense, immortal. Not all of them, it is true ; their immortality is but potential. Of about 60,000 immature ova in the ovaries of a young virgin, or of the half a million milliards of spermatozoa produced in the testicles during a man's lifetime, on the average perhaps half a dozen may achieve conjugation, and develop into new human beings. All the others will perish unutilised. But the few suffice to ensure the continuance of the species.

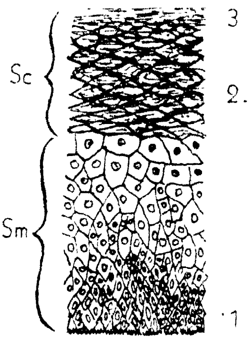

FIG. 35.—LAMINATED EPITHELIUM OF THE HUMAN SKIN.

Sm, stratum Malpighii (or rete mucosum) ; Sc, stratum corneum ; 1, young epidermic cells still undergoing multiplication , 2, moribund epidermic cells ; 3, cornefied epidermic cells.

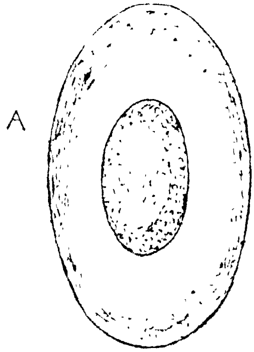

FIG. 36.—RED BLOOD-CORPUSCLES.

A, large nucleated red blood-corpuscle from the cave-olm ; B, non-nucleated human red blood-corpuscle.

BODY-CELLS AND GERM-CELLS

Very early, sometimes in the first segmentation of the fertilised ovum, the germ-plasm separates from the body-plasm ; that is to say the cell out of which the gonads or reproductive glands of the new organism will develop, detaches itself from the body-cells or soma-cells, and leads a quasi-independent existence. Only through these "germ tracts" (Weismann spoke of it as "the continuity of the germ-plasm") is the perpetuation of the species ensured in higher animals. In them, the reproductive substance is immortal (unless the whole species becomes extinct), whereas the individuals are, so to say, mortal buds which sprout for a brief time from this continuous germ-plasm. In many of the lower metazoa (multicellular animals), in which division of labour and cell-specialisation has not gone so far as in the higher metazoa, the possibility of asexual reproduction by budding or fission has been retained; and most of even the higher plants can be propagated by cuttings. But the molluscs and the articulata have already lost this faculty. It is, therefore, hardly an exaggeration to declare that in the higher animals the predominant, nay exclusive, functions are to provide shelter and nutriment for the reproductive cells hidden away within them, and to make arrangements for their conjugation in the sexual act. When the individual has fulfilled these duties, its part on life's stage has been played, and it must tranquilly accept death's summons. In many insects, the period of development to sexual maturity lasts several years, whilst the life of the sexually ripe insect is often measured in days. Indeed, many members of the animal kingdom cease to take nutriment once they are fully adult, and the intestinal canal atrophies. As soon as the reproductive act has been performed and the future of the eggs has been safely provided for, the parents die.—But I think you asked another question?

Continuity of the Germ-Plasm

Asexual Reproduction

Death and Reproduction

Renewal of Bodily Substance

B.—Yes, I want to know whether all the cells of the body are as short-lived as the red blood-corpuscles. It is popularly said that a man's body is completely renewed in the space of seven years.

A.—A renewal of material that has been worn out or used up, takes place in most of the tissues. You see this plainly in the growth of the hair and of the nails. Unfortunately we still lack precise information regarding the duration of life of the various kinds of cells. We can be fairly sure that capacity for cell-division tends to diminish with advancing years, and in many of the organs ceases altogether soon or late. Thus the power of forming reproductive cells is lost by the gonads, as a rule, somewhere between the ages of forty and sixty; and, generally, somewhat earlier in women than in men; but renewal of blood-cells and skin-cells goes on until the end of life. Strangely enough, cell-division ceases very early in the organs which rule the roost, in the brain and the spinal cord. It follows that the ganglion-cells of the central nervous system must

THE LONG-LIVED GANGLION-CELLS

be the most long-lived of all the cells in the body. Careful investigations have shown it to be probable that the very numerous ganglion-cells of our brain are all formed during intra-uterine life and have before birth lost the power to divide. Such increase in the size of the brain as subsequently occurs is chiefly due to the growth of the extant cellular elements. That, at any rate, is the opinion of Ribbert and other leading authorities. Perhaps memory is only rendered possible by the ganglion-cells being thus long-lived—and the failure of memory almost invariable in old age may be ascribed to senile degenerative processes in the same cells. (Under the microscope, signs of this degeneration are manifest—see below.)

B.—Then, if a man lives to be a hundred, his ganglion-cells, too, are a hundred years old ?

A.—Certainly ; and man is by no means the Methuselah of the animal kingdom. The giant tortoises of the Galapagos islands have been known to live three hundred years. Parrots and ravens can, it is said, survive to an age of two hundred. The age of the ganglion-cells of the respective creatures must be accordant. Of course the incapacity of the brain-cells to renew themselves must have a decisive influence upon the onset of old age and in determining the vital span. Like every other working machine, the ganglion-cells get worn out in time ; and, if premature death does not result from accident or illness, in the long run brain-death will result from failure of this part of our vital machinery. The " senile decay " and " softening of the brain " of folk-speech are more than mere metaphors.

THE BRAIN COMPARABLE TO THE BOILER OF A STEAM-ENGINE

B.—How does the brain get " worn out " ?

A.—Think of a steam-engine. At first the boiler is bright and clean ; but the longer the engine remains at work, the more do the tubes of the boiler become " furred ", with a consequent diminution of the capacity to generate steam-power. The engineer does his best to remedy the evil by chipping off the carbonate of lime, or by removing it with the aid of some chemical solvent. Still, as time goes on, the walls of the tubes suffer more and more, through oft-repeated furring and removal of fur, until at length the boiler has to be scrapped. Other parts of the machine may still be in good condition, but they are of no use, because the central organ, which supplied them with power, has decayed. Here, a new boiler may save the situation, but we cannot fit an old man or woman with a new brain. Degenerative changes in the ganglion-cells become manifest long before the machine strikes work altogether. Loss of memory has already been mentioned as a symptom of these. Certain products of tissue-change (like the fur in boilers) are inadequately eliminated from the ganglion-cells, and are stored up in the cell-body as pigment granules. (See Fig. 37.) This pigment is a lipoid, fatty substance. Like many other organs, the ganglion-cells are subject with advancing years to a kind of fatty degeneration, which here takes the form of the deposit of pigment granules, slowly progressive.

Activity of Phagocytes

Luckily in our body there are able engineers, who do their best to clear away this "fur" which hampers the working of the machine. This sanitary police-force consists of the white blood-corpuscles or leucocytes, which, in contrast with the red blood-corpuscles or "erythrocytes", are "entire" cells, provided with a well-developed nucleus.

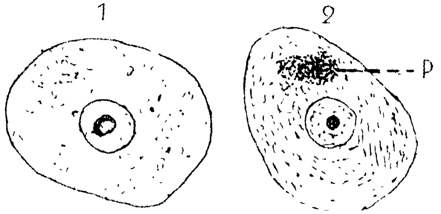

Fig. 37.—Ganglion-Cells from the Spinal Ganglia of the Guineapig. (After Mühlmann)

1, ganglion-cell devoid of pigment, from a guineapig one month old ; 2, ganglion-cell containing pigment (P), from a guineapig eighteen months old.

(See Fig. 38.) They have the structure and aspect of primitive protozoa, and a power of independent movement, crawling hither and thither like amœbas by thrusting out pseudopods ; and they can swallow and digest various small objects they encounter. They are therefore called phagocytes. (The phagocytes form only one of several kinds of white blood-corpuscles.) These phagocytes are able to quit the bloodvessels and wander through the tissues. If, for instance, pyogenic organisms (creators of festering or suppuration) enter the body through a wound, phagocytes flock to the threatened spot, eat up the microbes, and may be successful in preventing the onset of a serious illness. Under the microscope we can watch these phagocytes clustering round a ganglion-cell, entering it to cleanse it of pigment granules, which the phagocytes consume and digest. But just as a machinist cannot permanently prevent damage to the boiler of his engine by furring, so, with advancing years, the pigment granules accumulate in the ganglion-cells until they fill the whole cell-substance, in the long run slowly destroying the cell-body and the nucleus as well.

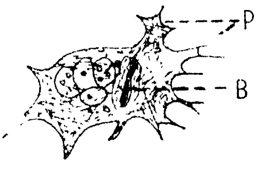

Fig. 38.—White Blood-corpuscle, which has swallowed a Bacterium.

P, pseudopod ; B, bacterium.

Brain Death

The other organs may still be sound, but the central nervous system can no longer fulfil its tasks, can no longer emit the stimuli needed to keep the rest of the body at work. When the functions of the brain are too gravely impaired, the activities of the dependent parts fail. In a steam-engine, sound wheels, pistons, and connecting rods can still be turned to account when the boiler has given out, can become parts of a new machine. Some organs of one who is dying from "brain death" might conceivably still be of use were they not so inseparably dependent upon one particular brain that its death involves the general destruction of the organism. Still, death is not a sudden coup, simultaneously involving all parts of the body. Even when the heart has ceased to beat, various cells live on, until at length corruption or necrosis overtakes them. When the safeguards provided by co-ordinate activity have been removed, they lose the power of resisting the germs of putrefaction.

B.—Your comparison to a steam-engine seems to me far-fetched. What warrant have you for saying that parts of an organism might survive its general death ?

ARTIFICIAL CULTURE OF ANIMAL CELLS

A.—Biological technique has been so far perfected that this is not a mere supposition. Despite the specialisation of animal cells that has resulted from the division of labour, many cells (especially in young organisms) retain so much independence that they can be cut out of the body and kept alive in artificial cultures just like protozoa and bacteria. For instance, cells have been taken from the heart of an embryo chick, and, kept in a nutritive medium, where they multiply by subdivision, have remained alive for twenty years without showing any sign of senility. Since barn-door fowls usually live about ten years, the embryo chick from which the before-mentioned cells were taken would, if allowed to grow up, have died ten years ago, but these heart-cells are still "going strong".

B.—Then what you said about the potential immortality of cells was seriously meant ?

NATURAL DEATH

A.—Yes, it was. The cell is not subject to natural death, that is to say to a death due to structural degenerative processes. Of course protozoa perish. Hour by hour, milliards of them are eaten by animals that prey upon them, or succumb to vicissitudes in the conditions of life. But these deaths are accidental, not natural. As contrasted with multicellular organisms, protozoa, having reached what may be called their standard size, have the power of rejuvenating themselves as soon as signs of senility appear. This rejuvenation goes hand in hand with reproduction. The fully grown, adult individual splits into two, in which its life is continued, there being no dead body to cumber the ground. In the metazoa, on the other hand, only the reproductive cells retain the power of generating new individuals out of themselves ; the body which acts as "host" to these reproductive cells will, sooner or later, undergo death and decay. Is the matter clear to you now ?

B.—What I can't understand is why a protozoon cannot go on living for ever as it is, without division.

TENSION BETWEEN NUCLEUS AND CELL-PROTOPLASM

A.—An explanation is provided by Richard Hertwig's theory of the relation between the nucleus and the cell-protoplasm. (See Fig. 39.) Recently it has been confirmed by Hartmann's experiments, though Hartmann interprets his results differently. In Hertwig's view there is in the cell a definite relationship between the growth of the nucleus and the growth of the cell-body. For a time, however, the cell-body grows through the absorption of nutriment, while the nucleus remains of almost the original size. The upshot is a tension between the nucleus and the cell-protoplasm; and this disharmony, says Hertwig, is the exciting cause of division. Shortly before division takes place, the nucleus, absorbing fluid from the cell-body, grows swiftly to double its previous size. In the daughter-cells resulting from division, the normal ratio of size as between nucleus and cell-body has been restored, and the tension has disappeared, to return with an overgrowth of the cell-body, which initiates a fresh division.

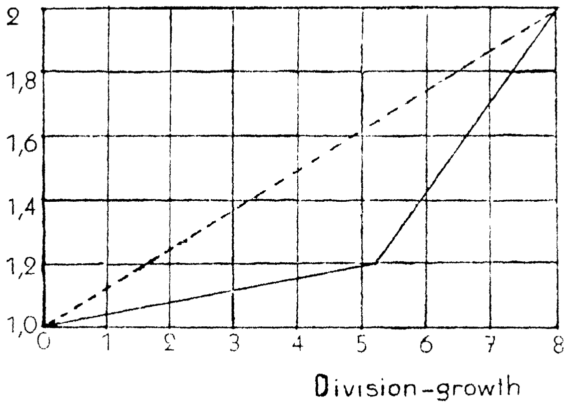

FIG. 39.—RELATION BETWEEN NUCLEUS AND CELL-PROTOPLASM.

Growth curve of the cytoplasm of an infusorium between two successive divisions. While during the hours 0 to 8 the growth of the cell-body goes on at a uniform rate, the nucleus grows slowly during the hours 0 to 5, and then rapidly during the three hours that precede the next division.

B.—What were Hartmann's experiments which confirmed Hertwig's theory?

A.—He showed that ageing of the cell could also be postponed by preventing division.

B.—How?

A.—Here was his guiding principle. Taking an amœba which had reached the size at which division is imminent, Hartmann, just when the division-growth of the nucleus was about to begin, cut off part of the cell-body. This sufficed, not only to prevent division, but also to promote the survival of the amœba without the onset of any signs of age. Thus Hartmann conferred on his amœbas a sort

EXPERIMENTAL IMMORTALITY

of experimental immortality.

B.—Did the animals thus mutilated remain smaller than their congeners ?

A.—No, they fed and grew like normal individuals until they regained the size at which division usually occurs ; and they would doubtless have divided had not Hartmann once more dispelled the tension between the cell-body and the nucleus by repeating the operation.

B.—What you told me about an artificial culture of cells taken from the heart of an embryo chick is possible, I suppose, only in the case of young, still undifferentiated cells ? Or can more highly specialised cells, such as have ceased to divide in their normal organismal environment, be stimulated to fresh division ?

A.—This question, which is tantamount to asking whether thoroughly differentiated cells can be rejuvenated, still lacks an answer. As we know from the observation of accidental and intentional (operative) wounds, many cells in a multicellular organism have by no means lost the power of reproducing themselves by division, though in normal circumstances they have no impulse to divide. When we stimulate them by making a wound, the dormant faculty for division awakens, and the cut tissues are more or less perfectly regenerated. (But in the higher vertebrates this regeneration is mainly restricted to the subdivision of connective-tissue cells to form a scar.) Uhlenhuth, taking epidermic cells from an adult frog—cells which in their normal surroundings have ceased to divide—has been able to induce them to divide in tissue-cultures. He found it impossible, however, to revive the faculty of division in ganglion-cells—in them specialisation had gone too far. Obviously, too, non-nucleated red blood-corpuscles cannot multiply by division.—But after our very discursive conversation, in which we have by no means limited our attention to tissue-change, we had better close down for the night.

TENTH EVENING

BUILDING MATERIALS OF THE ORGANISM

Giant Cells

A.—Yesterday you made the acquaintance of the amœba and had a glance into the laboratory of the cell. Towards the end we spoke of the extreme minuteness of many cells. If you've any questions to ask, go ahead.

B.—Are there, besides these tiny cells, others large enough for us to see them easily with the unaided eye ?

A.—You need hardly ask, for often you have found that two or three such cells make a hearty supper.

B.—What do you mean ?

The Hen's Egg is a Gigantic Cell

A.—Have you never eaten eggs ? A bird's egg, so long as it is unfertilised, is nothing but one huge cell, stuffed with vast stores of food for the nourishment of the embryo. (See Fig. 40.) The real cell, indeed, is the germinal disc, on the surface of the yolk, but in an ostrich's egg even this has a diameter of several centimetres. In mammals, on the other hand, among which the embryo grows for a long time within the maternal body and is nourished from the

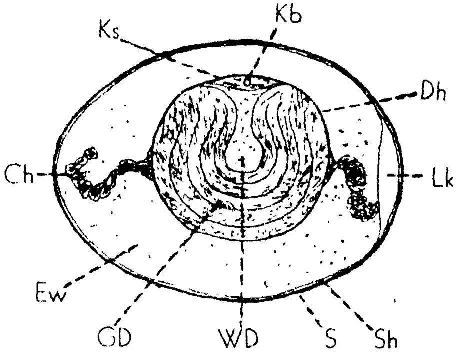

Fig. 40.—A Hen's Egg.

Ks, germinal disc ; Kb, germinal vesicle (nucleus) ; S, calcareous shell ; Sh, shell-membrane ; Ew, albumen ; GD, yellow yolk ; WD, white yolk ; Dh, yolk-membrane ; Ch, chalazæ ; Lk, air-chamber.

Caulerpa

mother's blood, the egg (egg-cell or ovum) is a very small structure, only just visible to the naked eye. In plants, too, we encounter giant cells, such as bast-cells which, though slender, may attain a length of eight inches. The marine alga, caulerpa, which may be as much as a yard long, and has a stalk, leaves, and roots, consists really of but one cell, which is, however, polynucleated.

The Amœba

A Sphere as the Ideal Form of Cell

Multiformity of Cells

Protoplasm

More important, nevertheless, than the varying size of cells, is, as far as concerns our present theme, cell-structure. Of it I can give you no more than a general outline, from which many deviations occur. This organism consists of a tiny drop of light-tinted, semi-transparent fluid which, like other drops of fluid, tends, unless otherwise influenced, to assume the most compacted volume for that amount of fluid, namely a sphere. Theoretically, a sphere is the ideal form of cell, though in nature this ideal is seldom realised. Even the amœba only adopts it when it enters what is known as the resting-stage. In multicellular organisms, mutual pressure and other influences result in the formation of cells of the most diversified shapes. We find cubes, discs, cylinders, ovoids, spindle-shaped, and branching cells. Indeed the shapes are almost innumerable, even in the case of the protozoa. But however much a protozoon or a unicellular alga may differ in appearance from any of the cells in the cell-community of our body, in their basic organisation all cells manifest a unity of type. Invariably there is a cell-body consisting of protoplasm, and invariably there is a nucleus. Apart from minor details, the main substance with which the chief vital functions of the cell appear to be associated is what is known as protoplasm. If, however, you ask me what protoplasm really is, I must regretfully admit that we know mighty little about the matter. From the chemical standpoint it is a highly complex colloidal compost subject to unceasing modification. In it are carbohydrates and fats ; but the dominant role is played by albumin, built up of the five elements hydrogen, carbon, oxygen, nitrogen, and sulphur. Numerous analyses of animal and vegetable cells have shown that the several elements just mentioned are present in remarkably equable proportions, except that in vegetable organisms there is a moderate preponderance of nitrogen.

B.—What are the proportions of the various elements ?

A.—Carbon comes first, to the amount of from 50 to 55% ; next oxygen, to the amount of from 19 to 24% ; next nitrogen, 15 to 19% ; next hydrogen, from 6·5 to 7·5% ; whilst sulphur brings up the rear, in an amount varying from 0·5 to 2%. Until well on into

Constitution of Organic Compounds in its Bearing on the Problem of Vital Force

the nineteenth century it was generally believed that the more intricate carbon compounds which (to the exclusion of carbonic acid, carbonic oxide, and the mineral carbonates) form the subject matter of what is called " organic chemistry " as distinguished from " inorganic ", could only be produced in the living body thanks to the effect of a mysterious vital force (vis vitalis).

Woehler's Achievement

Between inorganic and organic nature there seemed to be a great gulf fixed. But in 1828, Woehler, starting with the mineral salt ammonium cyanate, was able in his laboratory by heating this inorganic substance to effect the synthesis of the indubitably organic substance urea. The gulf had been bridged. Soon a number of other organic substances were built up by synthetic chemists : for instance, ethylic alcohol (spirits of wine), sugar, vinegar, and starch. At length Emil Fischer threw double sixes, first by successfully analysing the complicated organic substance albumin, and then producing it synthetically.

B.—If it is possible to achieve the synthesis of all the important organic compounds, then it can only be a step to the production of a simple living creature.

The Homunculus Delusion

A.—That is a typical " layman's error ". You err because you do not yet grasp the fundamentals of the problem, and therefore fancy it should be easy to make the homunculus. What you have to realise is that we cannot analyse living matter at all, we have to kill it first. We do not know what changes occur in the article of death. Albumins, though highly complex organic compounds, are quite as " dead " as any inorganic salt—sodium chloride, for instance.

Analysis of Albumins

Still, it remains Emil Fischer's ever-memorable service to have thrown a clear light on the chemical structure of the albumins, and to have shown that they consist of multifarious groupings of amino-acids. But the possibilities of these groupings are almost infinitely diversified. Out of 20 such acids there can be formed more than two thousand trillions of isomeric compounds, that is to say compounds made up of the same elements in the same proportions and having the same molecular weight, but differently grouped. How slender are the chances, amid all these possibilities, of hitting upon the precise arrangement which may be supposed to be the substratum of life !

The Enigmatic Vital Spark

Even if an experimenter did hit upon it, who could tell whether he would succeed in kindling the vital spark ? The living and the dead amœba consist of the same chemical substances, but one is alive and the other is dead. Ay, there's the rub ; there is the chasm which has not yet been bridged.

B.—You make the difficulty very clear.

ROLE OF THE INORGANIC CONSTITUENTS OF THE CELL

A.—We have not yet finished with the composition of protoplasm. In addition to the before-mentioned organic compounds, inorganic constituents are of considerable importance, especially in vegetable cells ; above all, chlorides and sulphates of sodium, potassium, calcium, and magnesium ; also compounds of phosphorus and iron. If the cell is to do its work properly, there must always be present a sufficiency of these substances. Should the percentage fall too low, the motor of life will cease working, though there may be a superfluity of all the other ingredients. Since the days of Justus Liebig, this has been described as the law of the minimum. Protoplasm always contains a large amount of water. Most of the compounds of which it is made up are present in watery solution. Many jelly-fish are 98% water ; and the water content of most cells must not sink below 70% if they are to keep going.

LAW OF THE MINIMUM

NINETY-EIGHT PER CENT OF WATER

B.—But surely our own body, with its firm bony skeleton, cannot hide away such quantities of water ?

A.—In a human fœtus at the end of the third month of intra-uterine life the proportion of water is 94% ; in a new-born baby it is still nearly 70% ; and not until old age does it sink to about 55%. The withdrawal of much of its water makes protoplasm hard and tough, and the vital functions flag, but are not necessarily extinguished. Many desiccated cells pass into a resting-stage, in which they may remain alive for ten years or even longer, their vitality reawakening when they are wetted.

DESICCATION AS A RESTING-STAGE

B.—I suppose the eggs of Triops cancriformis, about which you told me on our first evening, are in such a resting-stage of desiccation throughout periods of drought ?

MINUTE STRUCTURE OF PROTOPLASM

A.—A sound remark. We shall have a good deal to say later about desiccation and kindred phenomena, but our present business is to become more closely acquainted with protoplasm. Even under a low power of the microscope we can distinguish in protoplasm a clear, faintly tinted homogeneous ground-substance in which are imbedded numerous strongly refractile granules. A higher magnification shows us that these granules are the fine meshes of a network which pervades the ground-substance. They are, so to say, the partitions of a honeycomb seen in optical section. In other words, protoplasm has a spongy structure, the " holes " of the sponge being filled with a cell-sap which is more fluid than the partitions. (Refer back to Fig. 31, p. 123.)

A MIXTURE OF COLLOIDAL SUBSTANCES

B.—Excuse me for interrupting you. A while back you said that protoplasm was " a mixture of colloidal substances ", or words to that effect. I ought to have stopped you at the time, for I did not understand the word " colloidal ".

A.—A colloid is not a true liquid, but a fluid in which numberless fine solid particles are suspended. If you rub down Indian ink or lamp-black in water, the soot is not in either case (for Indian ink is also made of lamp-black, here held in a cake by animal glue) dissolved, but only suspended in very minute particles. By a stretch of the term solution, such a mixture is spoken of as a " colloidal solution ". Milk is also a colloidal solution, though there the suspended elements are not solid but liquid, tiny droplets of fat and albumin. It is better, in this case, to speak of a " colloidal emulsion ". By derivation, colloid means a gluey substance, as opposed to one which forms crystals, and a solution proper contains dissolved (not suspended) salts, etc., which crystallise out when the solution is super-saturated, i.e. has more of the salt or other crystallisable substance than it can carry at the extant temperature. Protoplasm is in the main a colloid emulsion, though it contains certain crystallisable ingredients. A true solution can pass through a filter so that its constitution is unchanged in the filtrate ; but when we have to do with a colloidal solution, a very fine filter, an " ultra-filter ", such as a collodion membrane, will separate out the colloid and undissolved substances. The solvent, which is really no more than a menstruum of suspension, makes its way through the pores, leaving the tiny particles behind. Protoplasm, then, is a mixture of two fluids, the droplets of one of these being imbedded among the lamellæ of the other. This spongy or honeycombed structure of protoplasm is of the utmost importance to the chemical and physical processes that go on in the interior of the cell. As Hofmeister insists, it would be more appropriate to describe the cell, not as a laboratory, but as a factory ; and to look upon each of these tiny sub-cells in the honeycombed structure of the protoplasm as a separate laboratory in which the chemical reactions go on more or less independently. Still, these Lilliputian laboratories are, of course, in close touch with one another ; and they can exchange their products through the partitions of the spongework. Not freely, however. The partitions function as semi-permeable membranes, letting some substances pass more easily than others, and to yet others putting up a notice " No Thoroughfare ". Thus the transmission of material through the interior of the cell is minutely regulated. Especially difficult is the permeation of the complex carbohydrates and albumins, whereas the simpler

COLLOIDAL EMULSIONS

A LIVING FACTORY

SEMI-PERMEABLE MEMBRANES

products of their splitting-up can be more freely interchanged. Thus by a suitable building-up or breaking-down, one of these sub-cells of the spongework can, in a sense, decide in case of need whether to retain a particular substance in its own interior or to allow it to diffuse throughout the cell. We have here a fresh example of the facilitation of tissue-change by the increase of absorbing and secreting surfaces, which we have already studied in the lungs, the blood-vascular system, and the alimentary canal.

B.—You have not yet explained to me what part the salts dissolved in the cell-sap play in the vital processes.

A.—I was just coming to that. Under certain conditions, the elementary particles suspended in the menstruum may become more firmly aggregated. The emulsion coagulates, passing from the condition of a pseudo-solution to that of a jelly. Then the process may be reversed, the elementary particles resuming a state of suspension in a pseudo-solution. Obviously this easy modifiability of the physical condition of the cell-content is of the utmost importance. If the cell-content coagulate beyond recall, the cell dies. This may result from exposure to high temperatures, as you can see any day when you boil an egg. Various kinds of cells differ greatly in their susceptibility to coagulation when heated. In many the albumin clots irrevocably at temperatures little above that of high fever (104° F). Others can endure a temperature of 158° F., which we find scaldingly hot, without being killed by coagulation of their albumin.

Coagulation Death

B.—In that case it must be theoretically possible for organisms to maintain life at a temperature of 158° F.

The Inhabitants of Hot Springs

A.—Not alone theoretically, but practically. In the hot springs of Yellowstone Park, where the waters gush forth from the earth at a temperature approaching 170° F., various algæ and bacteria have acclimatised themselves. This leads us to the part played by the inorganic salts dissolved in the cell-sap. According to modern views, these salts play a leading role in the processes of coagulation and fluidisation, thus hindering or favouring metabolic processes within the cell.

B.—Have all cells the above-described honeycomb structure?

Life-History of the Amœba

A.—In a good many, for example the amœba, even under very high magnification, we can only make out a homogeneous, hyaline (i.e. cloudily transparent) ground-substance, interspersed with innumerable granules. Now let us consider how the amœba spends its life. (Refer back to Fig. 30, p. 122.) If you place the animal in a drop of water under the microscope, it will, startled by the intensity of the light, contract into a little sphere. In this motionless globe, only a trained eye can recognise that it is a living organism. Soon, however, under the spur of hunger, slowly, hesitatingly, a projection forms somewhere on the surface of the protoplasm. It grows larger, and lobate, as more protoplasm flows into the base of the protuberance. Then other processes are thrust forth in the same direction, the remainder of the cell-body flows up to and around the processes (pseudopods, " false feet ", as they are called) ; and by these successive phases of the projection of pseudopods and flowing up to them, rather than by anything that resembles walking, the little drop of animated jelly crawls slowly in one direction or another. Apart from such " amœboid movements ", the protoplasm in the interior of the cell is in a perpetual flux. Like ants in an ant-hill, the tiny granules move, now up, now down ; now to the right, now to the left. This streaming movement of the granules is characteristic of protoplasm. We see it even in the cells of higher animals and plants, though these cells are restricted by a cell-membrane, and are therefore incapable of an amœboid movement from place to place.

Streaming Movement of Granules

B.—What force determines the streaming movement of the granules ?

A.—The granules do not move independently, but are borne hither and thither by currents in the cell-sap. The speed of the currents can be modified by stimuli of various kinds, can be increased or arrested. This shows that protoplasm is irritable, has sensation, How could life be maintained without the possibility of appropriate reaction to stimulus, and this implies sensation ? Unless the amœba had a sense of hunger, what should induce it to start on its peregrinations, and to ingest food ?

Protoplasm is Irritable

B.—I find it difficult to understand how a creature with no mouth can ingest food.

Absorption of Nutriment

A.—That is easier than you might suppose. If, when it is on the prowl for prey, an amœba encounters a nutritive organism or a grain of sand, the obstacle is grasped by two or more of the pseudopods, and the whole cell-body flows round it. A useless foreign body such as a grain of sand is, in the creature's further progress, simply ejected and left behind. But it is otherwise with nutritious particles ; these are robbed of their nutritive constituents, i.e. digested, and only the residues are extruded. The amœba shows an unmistakable power of " choice " ; algæ attract it more than does a grain of sand, and noxious materials are not ingested at all.

B.—How primitive it all is, and yet how purposeful !

Work done by Earthworms

A.—Many multicellular animals satisfy their hunger in a yet more primitive manner. The earthworm, for instance, simply eats its way through the humus. Whatever it finds digestible in the swallowed humus, is digested ; the indigestible grains of sand are evacuated by the anus. True, the creature also browses on mouldering leaves, which it drags into its burrow. Ordinarily the humus consumed by earthworms comes from considerable depths, and the residues, mixed with the worm's intestinal secretions, are voided above ground, near the aperture of the tunnel, forming what is known as a worm-cast. Often in the early morning you must have seen the lawn thickly bestrewn with these little pyramids of earth. By thus ploughing, aerating, and manuring the soil, earthworms do work that is extremely useful to man. According to Darwin's careful estimate, during one year earthworms swallow, bring to the surface, and void there more than 18 tons of earth per acre.

There are many of the higher animals, too, which are nowise fastidious, but bolt whatever comes within reach of their mouths. Everything is grist to their mill. Enough to watch how goldfish are continually opening their mouths as they swim, swallowing water, and with the water any little organisms and dirt-particles it may contain. The water flows out through the gill-clefts, which are beset with thorns and other appendages to form a sieve, the solid substances, except those that are fine enough to pass the sieve, being retained in the gullet and swallowed.

Structure and Environment

B.—I listen, wonder, and fail to understand. When the amœba moves about, projects pseudopods, seizes and digests nutritive materials, it does mechanical work. The energy required for the performance of this work is derived from its food. That is comprehensible to me. But for the performance of any mechanical work, an implement is needed as well as a source of energy. Now the body of the amœba is fluid, devoid of structure and unprovided with organs. The creature has no organs of special sense, no eyes to see with, no ears to hear with, no organs of taste or smell—no means of distinguishing one thing from another. I find it inconceivable that so primitive an animal can continue to exist.

A.—You are emptying a sackful of difficulties. Many of them are due to your contemplating the problem from too exclusively human an outlook. To use a phrase of Uexküll's, you must, as it were, think yourself into the amœba's skin. Its environment is entirely different from ours ; but the creature is as well adapted to its environment as we are to the conditions of our own existence—perhaps better adapted than we. Colours, tones, tastes, and smells, presumably do not exist for the amœba. Nevertheless it perceives stimuli of different strengths, reacting differently as the strength varies, just like ourselves. Besides, what we see, touch, smell, hear, and taste, is not the real world, but only world as mirrored by our senses and interpreted by our intelligence. Then there are limits to the capacity of our sense-organs, highly subtilised though they are. If four hundred billions of etheric undulations per second

The Real World and the World of our Senses

Limitations of the Sense-Organs

impinge upon the retina, we have the sensation of red; if the number increases to seven hundred billions, the sensation of blue. But no matter whether the retina be stimulated by etheric undulations or by an electric current or by a blow, the only sensation produced will be light. Similarly, anything that stimulates the auditory nerve produces sound. Our eyes are unable to perceive infra-red and ultra-violet radiations, although we become aware of the former through their evoking a sensation of warmth, and of the latter by certain chemical effects. There may be animals which excel us in this respect, being able to perceive rays outside our visible spectrum.

High Notes

The same thing applies to tones. There are very high notes which our ears are too dull to perceive. The love-song of male crickets and grasshoppers is partly composed of such tones, but the females of the species in question hear them and are allured by them. Here, then, crickets and grasshoppers are better equipped than human beings.

B.—How do you know that the amœba reacts differently to different stimuli?

A.—I asked it, and it told me.

B.—What do you mean? An amœba cannot speak.

Value of Experiment

A.—No, an amœba cannot speak; but if you put your questions rightly, it will answer them. When, during scientific investigation, simple observation leaves us at a loose end, we have recourse to experiment. What is an experiment but a question put to nature, and one which is promptly answered if the question be rightly asked? Very elementary experiments suffice to show that amœbas are sensitive to stimuli. If you project a pencil of bright light into a drop

Heliotropism

of water containing various kinds of protozoa, you will find that some of them seek to evade the light, whilst others cluster where it is strongest. The latter reaction to stimulus is called heliotropism. Similarly with many chemical stimuli. The amœba will flow round an alga or a grain of sand, but will retreat from a poisonous salt. It follows that (though in another way than ourselves) these creatures perceive specific stimuli, and are aroused by them to perform actions essential to self-preservation. Now as to your second question,

The Amœba's Tools

what enables an amœba, structureless though it be, to creep in a particular direction and to do work though it has no organs? As a matter of fact, the amœba is not structureless. It has a variable instead of a fixed structure. As I told you before, living protoplasm can, with the collaboration of the inorganic salts it contains, pass from the fluid into the gelatinous state. That is to say it can coagulate. This coagulation does not affect the whole body uniformly. While coagulation is going on in one region, fluidisation may be taking place in another, so that inconstant structures are formed. Let us suppose that in the "honeycomb" thus arising, a concentrated solution of certain salts has accumulated in particular compartments. Then, according to the degree of concentration, fluid will tend to flow from the compartments containing a weaker solution into the compartments containing a stronger solution until the degree of concentration in the respective areas has been equalised. That would give a plausible explanation of the protrusion of the pseudopods and of the crawling movement of the amœba. You are quite right in saying that an amœba has no tools, no implements, no organs, of a fixed kind. But, as you can see in the pseudopods, it can improvise organs for the occasion by processes of transient liquefaction and coagulation. We human beings need constant organs, in order to cope with our environment; and even when, at the moment, there is nothing for them to do, we have to carry them about with us and nourish them. Amœbas improvise their organs as required, and reabsorb them into the cell-body when done with. For their environment, transient organs suffice. Also, nutritive particles are not simply ingested into the cell-body, for, at the moment of their entrance, the cell-substance, the plasma, that surrounds them stiffens into a thin enveloping membrane, forms a tiny sac filled with fluid, in which the food is immersed. This nutritive vacuole, as it is called, is a sort of primitive stomach, in which digestion takes place. Not until the food-substances have been split up and liquefied, do the contents of the vacuole ooze into the environing protoplasm and become transformed into new cell-substance. The indigestible residues are extruded with the vacuole.

Degrees of Concentration

Improvised Organs

Nutritive Vacuoles

B.—I find it very difficult to break away from the human standpoint, and to regard nature objectively. But go ahead.

Nucleus and Cell-Protoplasm

A.—If you watch an amœba for a short time only, you may get the impression that the protoplasm of the cell-body is alone concerned with the carrying on of the creature's vital functions, for visible changes occur only in the cell-body while the nucleus apparently remains inert. But we must not jump to conclusions. Inconspicuously, the nucleus presides over all that is going on. As regards the structure of the nucleus, I must likewise be content with an outline sketch. The size of the nucleus is, like the size of the cell, variable. Speaking generally, there is, for each kind of cells, a fairly stable ratio between the size of the nucleus and the quantity of the

Peculiarities of the Nucleus

surrounding cell-protoplasm. Thus the large ganglion-cells of the spinal cord have enormous nuclei, which are visible to the naked eye and can be dissected out with the point of a needle. Very big, in proportion to the cell-body, are the nuclei of unripe ova. On the other hand, in ripe and in fertilised ova the nucleus is at times so small that its presence may even be hard to demonstrate. Normally the nucleus is situated near the middle of the cell, but it lies sometimes a good deal to the side, though always surrounded by cell-protoplasm. The varying reaction of different constituents of the nucleus to certain dyes (such as hæmatoxylin, carmine, thionin, etc.) enables us to distinguish the chromatin, which stains deeply, from the achromatin or linin, which stains little if at all. In structure the nucleus resembles on a smaller scale the cell-body. Its ground-substance consists of a clear fluid, the nuclear sap, which comprises the bulk of the nucleus. Imbedded in this juice is a meshwork or spongework of linin which in optical section gives the impression of a honeycomb cut across. When the nucleus is quiescent, the chromatin is usually dispersed in the form of minute granules, clinging to the fibrils of linin, and especially conspicuous at the intersections of the meshwork. (Refer back to Fig. 31, p. 123.) The chromatin is the most important of all the constituents of the nucleus. This remarkable substance is the carrier of heredity, by which I mean that through its instrumentality the reproductive cells transmit the characteristics of the parents to the children. All changes in type as between one generation and another are attributable to changes in the nuclear chromatin. No, don't ask me how we know this. The matter must stand over to another day.

REACTION OF NUCLEUS TO STAINS

CHROMATIN

B.—Has the nucleus a limiting membrane, and is there never more than one nucleus in a cell?

NUCLEAR MEMBRANE

A.—As to the universality of a nuclear membrane, we are not quite clear. Certainly the nuclei of some kinds of cells have such membranes, those of other kinds perhaps not. The general rule is for a cell to have only one nucleus, but we know of both vegetable and animal cells which have two, three, and even more nuclei. In many organisms (certain bacteria, for instance) there is no circumscribed nucleus, the chromatin being dispersed throughout the cell-body. We do not know whether this is a primary condition or a reversion. In most animal cells there is found adjoining the nucleus a tiny, strongly refractile body, much smaller than the nucleus, and probably derived therefrom. It is known as the centrosome. (Refer back to Fig. 31.) This little granule plays an important part in connexion with cell-division. We get the impression that it functions

CENTROSOME

as the director of the movements of the various parts of the cell and the nucleus during that process.

VEGETABLE CELLS

The structure of plant-cells is somewhat different from that of animal cells. The former, in multicellular plants, are always surrounded by a more or less rigid cell-membrane, which makes them cells (little boxes) in the original sense of the term. The cells of the leaves and other green parts of plants contain granules of a substance called chlorophyll, to which the green colour is due. (Refer back to Fig. 29, p. 121.) We must regard these teeny-tiny corpuscles with due reverence, for in the last analysis all life on earth depends on their activity. They are the " synthetic chemists " of the organic world, being unique in their power to build up organic compounds out of inorganic materials. Under the influence of sunlight they take up carbonic acid out of the air, and manufacture starch. Not until Woehler's great achievement did man show himself a competent rival of the chlorophyll granules.—Well, now that you have learned the elements of cell-structure, we can go on to consider the functions of the various parts of the cell.

CHLOROPHYLL AS THE FOUNDATION OF LIFE

B.—That is what I am keenest upon. Frankly, I am puzzled as to how the functions of such tiny structures can be learned.

A.—As in the study of all natural phenomena, two roads are open to us, observation and experiment. If you watch a vegetable cell engaged in strengthening its enclosing membrane here or there by the deposit of fresh layers of cellulose, you will see the nucleus leave its usual post in the middle of the cell and move towards the spot where repairs are going on. When these repairs are finished, it returns to the middle. Now for another example. While in a growing ovum the nutritive yolk or yelk is being prepared, the nucleus thrusts out long pseudopod-like processes, and the deposit of yelk is richest where these point. We derive the impression that the nucleus acts as director, not only of repairs, but also of the manufacture of nutriment for the embryo-to-be.

THE NUCLEUS AS A REGULATOR OR GOVERNOR

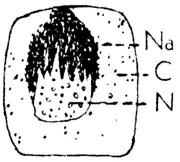

FIG. 41.—OVUM OF A WATER-BEETLE.

C, cytoplasm ; N, nucleus ; Na, nutritive yelk. The nucleus has thrust forth pseudopods in the direction where the yelk is being most briskly deposited.

B.—The proof seems to me insufficient. If an excavation is being made, and inquisitive persons flock to the edge in order to watch the workmen who, below the level of the soil, are busily shovelling out sand and stones, a casual observer at some distance might well believe that the idlers were participating in the work.

A.—I was talking, not of proof, but of probability. But the evidence furnished by experiment is unambiguous. If with a sharp dissecting

THE CELL-BODY IS NON-VIABLE IN THE ABSENCE OF THE NUCLEUS

needle you divide an amœba into two portions, one of which contains the nucleus, while the other does not, you will find that only the former will go on growing until it becomes an amœba of normal size. The portion with no nucleus will soon perish, even if it be the larger. By this and many similar experiments it has been shown that the cell-body is non-viable in the absence of the nucleus, for the nucleus directs all the metabolic processes in the cell. But the nucleus needs the protoplasmic cell-body quite as much as the cell-body needs the nucleus. In specimens of a large marine protozoon, Thalassicola pelagica, Verworn was able to dissect out the nucleus without injuring it. He found that these detached nuclei invariably perished. They could only survive if at least a narrow fringe of protoplasm was left surrounding them. But in that case the animal was able to regenerate itself integrally. To-day we can be fairly certain that the cell-body is mainly concerned with motility and the ingestion of food, whereas the nucleus directs metabolism and acts as regulator of most of the vital functions.

BRICK AND MASTER-BUILDER SIMULTANEOUSLY

When, yesterday, I asked you what cells were, you replied that they were the building materials, the bricks of the organism. That is correct, but your answer is one-sided, and fails to give the cells due credit. They are not only bricks, but also architects, since they can grow, by division can produce new bricks, and can so dispose of themselves as to build up the various tissues and organs of the body.

ORGANISM AND MACHINE

Here we touch the weak point in the otherwise apt comparison of the organism to a machine. The organism has powers which transcend those of a machine. No machine can reproduce itself "on its own", or renovate itself, or spontaneously reproduce a lost part. Decades of arduous research have been needed to give us a sound understanding of what is happening in cells when they multiply. People used to be fond of comparing cells to crystals. One reason

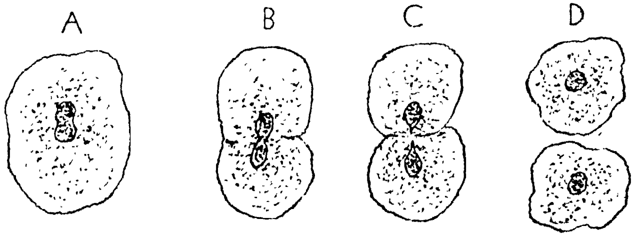

FIG. 42.—AMŒBA DIVIDING.

A, the cytoplasm and the nucleus begin to undergo longitudinal distension ; B, the nucleus becomes constricted in the middle, and the cell-body begins to divide ; C, the division of the nucleus is finished, while the constriction of the cell-substance between the parts which will form two daughter-cells is accentuated ; D, division is complete.

for this fallacious comparison was that Schleiden and Schwann, the founders of the cell-theory, held quite erroneous views concerning the origin of new cells, believing that cells crystallised out of a germinal substance (" blastema ") as crystals form in a super-saturated solution.

Omnis Cellula e Cellula

Mohl, Remak, Virchow, and others showed that new cells only arise by the division of pre-existent cells ; and Virchow coined the aphorism which has become classical, " Omnis cellula e cellula." We might supplement this by saying, " Omnis nucleus e nucleo," for every nucleus is produced by the division of a pre-existent nucleus.

B.—If you are not tired, I should like to know exactly how multiplication of cells and nuclei takes place.

Cell-Division

A.—Consider the simplest case, to begin with. You know that the red blood-corpuscles of man, though non-nucleated, are formed out of nucleated cells. In young nucleated red blood-cells, the process of division can be easily watched under the microscope. The cell-body undergoes elongation ; then it is strictured round the middle ; next the nucleus assumes a finger-biscuit shape, and then divides into two nuclei, which move apart into opposite poles of the strictured cell. Now the stricture cuts each pole completely away from the other, so that we have two small nucleated cells in place of one larger one. These small cells grow for a time, and then repeat the process ; or else they get rid of their nuclei and become ordinary non-nucleated red blood-corpuscles.

B.—How simply this important process runs its course !

Indirect Cell-Division

A.—It is only simple in cells of a simple kind, which are, so to say, guests in the body, and are foredoomed to a speedy death. In more long-lived and more vigorous cells, division takes place in a way which allots perfectly equable shares of the nuclear chromatin to the two daughter-cells. (See Fig. 43.) This indirect division (mitosis is the technical term) is initiated by the partial fusion of the chromatin granules interspersed throughout the nucleus, so that they form a single, much convoluted filament. Simultaneously the centrosome, the little body which lies in the plasma adjoining the nucleus, subdivides, and the two parts move to opposite poles of the cell, but remain connected by a sort of spindle, a fusiform arrangement of excessively fine fibrils. (See Fig. 43, 4.) Radiations also pass from them towards the periphery of the cell, so that they look like two tiny suns. The nucleus lies between them, in the middle of the spindle. Meanwhile, remarkable changes are going

Chromosomes

on in the nucleus. The long, convoluted thread of chromatin has broken into a number of detached loops called chromosomes, the

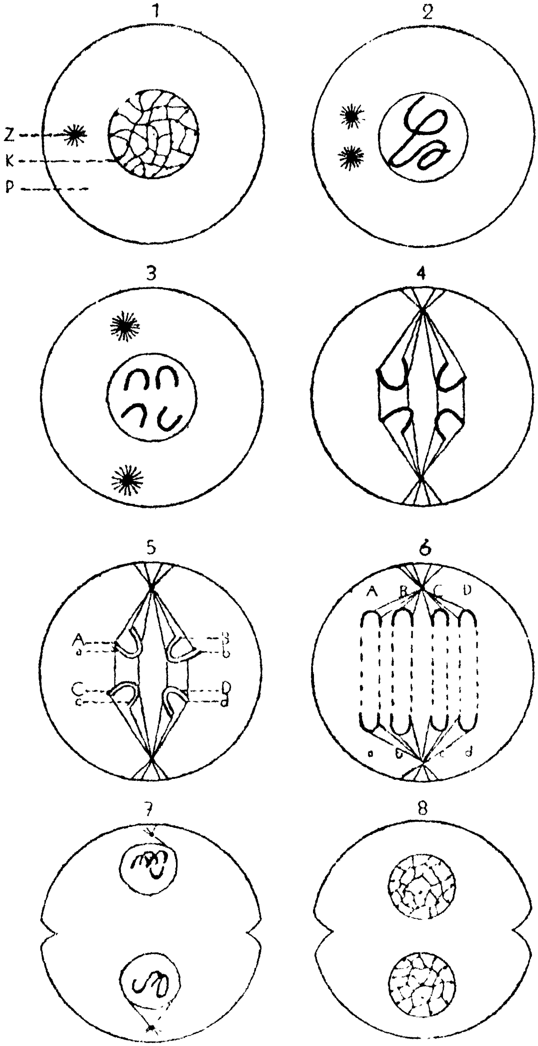

FIG. 43.—DIAGRAM OF CELL-DIVISION, IN EIGHT PHASES.

1, quiescent cell; P, protoplasm; K, nucleus; Z, centrosome; 2, the centrosome has divided, and the parts are migrating towards the poles of the cell; the nuclear chromatin has formed itself into a convoluted thread; 3, this thread has divided into four chromosomes, 4, phase of the equatorial plate; the nuclear membrane has disappeared, and the four chromosomes have arranged themselves as the equatorial plate; a spindle-figure radiates from the centrosomes; 5, formation of the daughter-plates; the chromosomes have split longitudinally; the paternal segments are marked A, B, C, D, and the maternal, *a*, *b*, *c*, *d*; the respective groups of segments are about to migrate towards the opposite poles of the cell; 6, phase of the daughter-plates; 7, in the daughter-cells, the chromosomes are coalescing into nuclear filaments; round each filament, a nuclear membrane is re-forming; 8, nuclear division is over; the spindle-pattern of radiations has vanished; the two daughter-nuclei have returned into a resting-stage; the chromosomes have disappeared; the cell-body is being strictured, and will soon separate into two cell-bodies, one for each nucleus.

number varying from species to species, but being constant in the cells of any particular species. The smallest known number of

NUMBER OF CHROMOSOMES

chromosomes, namely two, is found in one of the parasitic intestinal worms; the largest number, 124, in a small crustacean, artemia. The cells of the human body contain 48. This last is one of the commonest numbers, other common ones being 2, 8, 12, 14, 16, and 24.

B.—Upon what does the number of the chromosomes depend, and why are they always present in an even number?

A.—We do not know upon what the number depends, but at any rate it has nothing to do with the grade of organisation of the animal or plant in question. The number is always even because in the fertilised ovum half of them are derived from the unfertilised ovum and half of them from the spermatozoon; and since all the cells of the body are produced by division and subdivision of the fertilised ovum, the number of the chromosomes must necessarily remain even. The only exception to the foregoing rule occurs in the case of the mature male and female reproductive cells, for in these the number of chromosomes is reduced to the half of that in the body-cells. For instance, an animal having four chromosomes in the body-cells, will have only two in the reproductive cells after maturation of these; one with fourteen chromosomes will have seven in the reproductive cells; and so on. But the addition of the seven chromosomes of the spermatozoon to the seven chromosomes of the unfertilised ovum, will result in the fertilised ovum having fourteen, an even number once more.

Let us follow the process of cell-division farther. As soon as the chromosomes have formed out of the convoluted filament of chromatin, the nucleus disappears as a distinct structure, the nuclear membrane having vanished, so that the chromosomes appear to lie free in the protoplasm. Careful examination will show, however, that each chromosome remains attached to one of the threads of the aforesaid spindle, those which radiate from centrosome to centrosome. Impelled by a mysterious force, the chromosomes move along

FORMATION OF THE EQUATORIAL PLATE

the threads of the spindle towards a plane lying half-way between the two centrosomes, where they arrange themselves in what is called the equatorial plate lying at right angles to the axis of the spindle. If we contemplate it from the direction of one of the poles, we see the chromosomes disposed circularly in this equatorial plate. Now

LONGITUDINAL SPLITTING OF THE CHROMOSOMES

something still stranger happens. Each chromosome splits longitudinally into two precisely similar rods or loops. Then the filaments of the spindle contract like stretched rubber, drawing one half of each split filament to the respective poles of the cell. Now the halves of the chromosomes are arranged in daughter equatorial plates, each of which is adjacent to one of the daughter centrosomes.

Thus the chromatin of the mother-nucleus is equably apportioned to each of the daughter-nuclei, and therefore to the daughter-cells, each of which must have the same number of chromosomes as had the mother-cell.

B.—What is the significance of this careful assignment of the chromatin of the mother-cell to the daughter-cells ?

CHROMATIN AS THE CARRIER OF HEREDITY

A.—Soon after its discovery, this peculiar distribution of the chromatin made biologists infer that the substance must play some decisive part in the life-history of the organism. Before long, the suggestion was made that chromatin must be the carrier of heredity, must be the enigmatic instrument through which the qualities and characteristics of the parents (variously mingled) come to be reproduced in the offspring. Let us assume that each chromatin granule seen on the meshwork of the nucleus in its resting-stage can transmit a particular inheritable quality or characteristic. Before the nucleus starts to divide, these chromatin granules arrange themselves in a continuous thread, strung, as it were, like beads on a string. Then this convoluted thread divides into segments, the chromosomes, and the chromosomes dispose themselves in the equatorial plate. If each daughter-nucleus is to receive an equal share of every heredity factor or unit, the only possible way is that which actually occurs, namely that the chromosomes should split longitudinally, and the split halves move to different poles of the cell where they will become the chromosomes of the daughter-nuclei. When matters have gone so far, a furrow begins to form round the equator of the mother-cell, and extends inward until two daughter-cells have been produced, two hemispheres separated by a thin party-wall. Division is now complete, and a reverse process sets in in the nuclei of the daughter-cells. The chromosomes coalesce into a convoluted thread, and then become the mesh-work typical of a nucleus in the resting-stage. The radiations of fine fibrils from the centrosomes vanish, and the now quiescent cells, absorbing nutriment, grow until they reach the original size of the mother-cells. If we suppose the chromatin granules, likewise, to have regained the size of those in the mother-cell, the daughter-cell is once more ready for division.

INDIVIDUALITY OF THE CHROMOSOMES

B.—If the chromosomes break up completely into the chromatin granules, are entirely separated into distinct heredity factors, it seems strange to me that in a new division of the cells these heredity factors should always be rearranged in the old way. (See Fig. 44.)

A.—Presumably the breaking-up is no more than apparent, for in actual fact the chromosomes always reappear in the same form and number. Like every machine, however, this mechanism of division can occasionally get out of gear. A superfluous chromosome may slip into a daughter-cell. When that happens, the daughter-cells in successive divisions will continue to have this supernumerary chromosome. We may assume, therefore, that the chromosomes, though no longer distinguishable as such, retain their individuality even in the quiescent nucleus.

B.—I have not yet grasped what forces are at work to bring about the longitudinal splitting of the chromosomes, and to make the respective halves move towards the poles of the cell.

A.—I could only tell you that if I knew more than any contemporary biologist. We can watch the processes I have described, and can make a shrewd guess at their purpose; but the essential nature of the forces which bring to pass so wonderfully fair and accurate a distribution of the heredity factors, is still unknown. It is true that attempts have been made to explain the phenomena of mitosis mechanically, and that comparisons have been drawn between the fusiform radiations that connect the centrosomes, on the one hand, and lines of magnetic force, on the other. Experimenters have been able, in gelatinous froth and in very thin sheets of rubber, to produce figures resembling those seen in nuclear division or mitosis; but these are only superficial analogies. As Yves Delage once wrote, it would be as wrong-headed to regard the signs of the zodiac known as Leo, Libra, and Pisces as a real lion, real scales, and real fish, as it is for many experimenters to esteem their mechanically imitated cell-structures as real cell-structures and real mitotic figures.

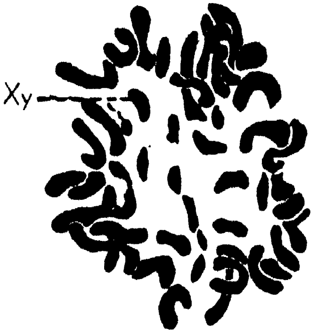

FIG. 44.—PAIRED CHROMOSOMES FROM THE SOMATIC (BODY, NOT REPRODUCTIVE) CELLS OF A HUMAN BEING. (After PAINTER.)

Xy, the two sex-determining chromosomes.

ARTIFICIAL MITOTIC FIGURES

B.—Please tell me why and how the number of the chromosomes is halved in the ripe reproductive cells.

A.—Better leave that till to-morrow, when we shall consider the subject of fertilisation. Good night!

ELEVENTH EVENING

MECHANISM OF FERTILISATION

Structure and Origin of the Reproductive Cells

B.—I have found the time drag until this evening, for fertilisation with all its consequences has always seemed to me one of the most enigmatic of vital manifestations.

A.—You will still have to exercise a little patience, since we must first consider the structure and origin of the reproductive cells, and you must become acquainted with the preliminaries that occur when they are ripening for the act of conjugation. Although the mature ovum and the mature spermatozoon differ so greatly in size and aspect, they are kindred structures. We learn this from the history of their development. The young spermatozoa and the young ova that are formed in the respective male and female gonads are barely distinguishable from one another. Indeed it is possible to bring influences to bear which will transform young ova into spermatozoa and young spermatozoa into ova. If we examine the male gonads or testicles of an adult animal, we find that it contains numerous cells which represent various stages on the way to become spermatozoa. The first stage is a fairly large cell that originates in the wall of a seminal tubule, and is called a spermatogonium ; this divides into two smaller cells known as spermatocytes (there are two generations of these, primary and secondary). Spermatocytes divide into still smaller cells, the spermatids. Without division, but through structural changes, the spermatid develops into a spermatozoid or spermatozoon. Considering this succession of generations—spermatogonium, primary spermatocyte, secondary spermatocyte, and spermatid—you see that the spermatogonia and the spermatocytes, which look much like any other cells, are, so to say, great-grandparents, grandparents, and parents of the spermatozoa. (See Fig. 45.) The spermatogonia and spermatocytes have the full equipment of chromosomes characteristic of the species of animal with which we are concerned. Chromosomes may vary a good deal in shape in certain animals, whose cells may contain rod-shaped, looped, comma-shaped, spherical, etc., chromosomes—always in pairs.

Transformation of Ova into Spermatozoa

The Spermatozoa

B.—I suppose that one partner of such a pair comes from the father and one from the mother ?

A.—That is so. But we must not anticipate. You will hear all about it when I come to the description of fertilisation. When a primary spermatocyte is about to divide, as a stage on the way to the formation of a mature spermatozoon, we see that corresponding chromosomes

PREPARATION FOR THE REDUCTION DIVISION

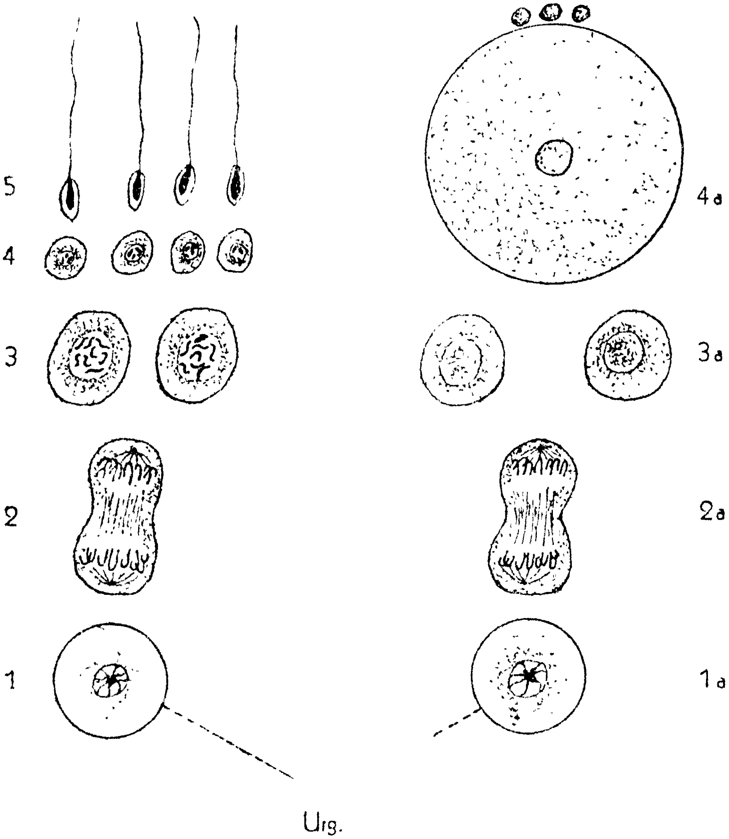

FIG. 45.—DEVELOPMENT OF SPERMATOZOA AND OVA (MALE AND FEMALE GAMETES) OUT OF SPERMATOGONIA AND OVOGONIA (URG) RESPECTIVELY.

1, spermatogonium ; 1*a*, ovogonium ; 2, spermatogonium dividing ; 2*a*, ovogonium dividing ; 3, primary spermatocytes ; 3*a*, primary ovocytes ; 4, four spermatids produced by the division of two spermatocytes ; 4*a*, four cells produced by division of ovocytes, the large mature ovum and the three polar bodies ; 5, the mature spermatozoa produced by the transformation of the spermatids.

arrange themselves pairwise in the equatorial plate. The typical spindle-shaped pattern of fine filaments radiating from the centrosome makes its appearance. But whereas in every other cell-division the chromosomes split longitudinally—so that at this stage, just before

HALVING OF THE NUMBER OF CHROMOSOMES

division, the nucleus has double the number of chromosomes typical of the cells of the species concerned—in the reduction-division no longitudinal splitting of the chromosomes occurs. The paired chromosomes simply detach themselves from one another, and one set goes to each pole of the cell. (See Fig. 46.) Now the cell-body is strictured, and the two daughter-cells are formed, each of these

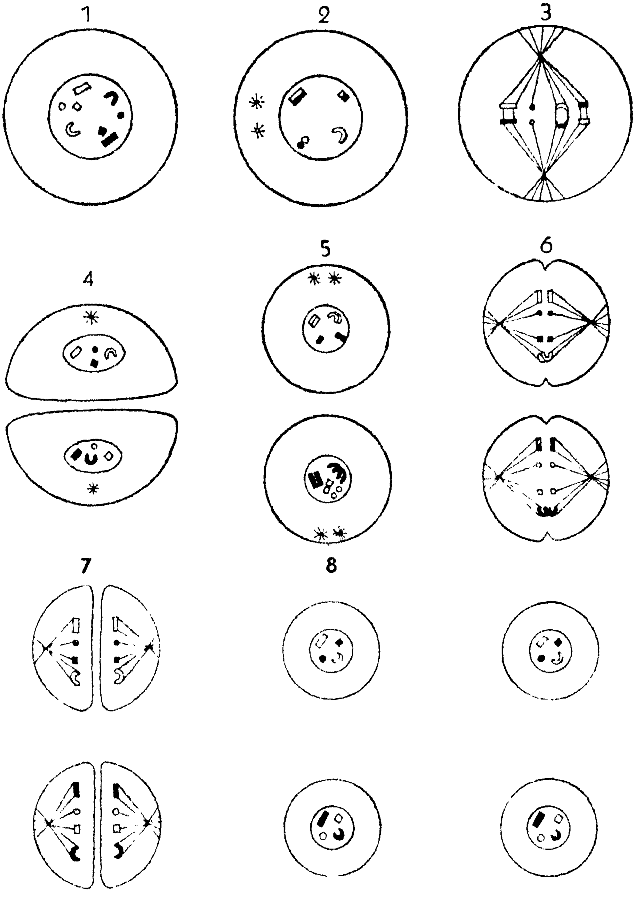

FIG. 46.—REDUCTION-DIVISION OF THE SPERMATOCYTES, IN WHICH THE NUMBER OF THE CHROMOSOMES IS HALVED.

1, the immature sperm-cell contains eight chromosomes, four (white outlines) derived from the mother, and four (black) derived from the father; 2, the chromosomes arrange themselves in pairs; 3, the chromosomes have formed the equatorial plate, and the chromosomes of paternal and maternal origin respectively are passing towards the poles of the cell, where they will become constituents of the daughter-cell in each case. Since there has been no splitting of the chromosomes, the nucleus of each daughter-cell contains only half as many chromosomes as did the nucleus of the mother-cell; hence this division, which occurs at maturation, is called the reduction-division. 4, the daughter-cells thus produced; 5, the two daughter-cells are about to redivide, and their chromosomes have split; 6, phase of the equatorial plate; 7 and 8, the four mature spermatozoa resulting from the division of the two daughter-cells.

daughter-cells having in its nucleus only half the normal number of chromosomes, the chromosomes being some of them the paternally derived elements and others of them the maternally derived elements of the original pairs of chromosomes. The halving of the number of chromosomes, which is necessary to the maturation of the spermatozoon, has thus been effected in the simplest possible way. Without passing into a resting-stage, a fresh division takes place, which proceeds in the customary fashion with splitting of the chromosomes, and serves only to produce four daughter-cells out of the two. Thus out of the primary spermatocyte arise two secondary spermatocytes, and then four spermatids, which transform themselves into ripe spermatozoa. In this transformation, most of the protoplasm is discarded; the nucleus becomes the head; the centrosome, the shank; and what is left of the protoplasm, the tail. The upshot is that in most animals the spermatozoa have very little resemblance to ordinary cells.

B.—If I understand you aright, out of each primary spermatocyte there are produced by two successive divisions without a resting-stage four spermatozoa. By the first of these divisions, the reduction-division, the number of the chromosomes is halved; but the second division proceeds in the ordinary way.

A.—That is so. By undulatory movements of its tail, a spermatozoon in a suitable fluid can traverse fairly long distances. For this minute creature, measuring only 2 microns, it is a long way from the vagina into the interior of the uterus; and often the spermatozoa make their way farther still, into the Fallopian tubes. What guides them on their adventurous voyage, you will learn when we come to speak of fertilisation. (See Fig. 47.)

B.—I suppose that a similar reduction-division to halve the number of the chromosomes must occur during the maturation of the ovum?

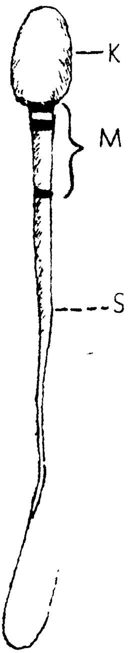

Fig. 47.—Human Spermatozoon, greatly magnified.

K, head, representing the nucleus; M, shank, representing the centrosome; S, tail, representing the cell-body.

Reduction-Division of the Ovum

A.—Certainly. Substantially the process is the same. Out of every ovocyte there arise, by two successive divisions without a resting-stage, four cells, only one of which is a mature ovum, whereas the others, known as the polar bodies, are non-viable, and speedily perish. But you will want fuller details. First of all, the nucleus of the ovocyte migrates to the periphery of the cell; the chromatin filament divides itself into or arranges itself as chromosomes, which, after splitting longitudinally, dispose themselves in an equatorial plate. One set of the products of this cleavage remains in the ovocyte, and around the other set there aggregates a minute quantity of the cell-body or cell-protoplasm, the resulting tiny cell being budded off from the large one (extrusion of the first polar body). The first division is finished. The chromosomes remaining in the secondary ovocyte now, without a resting-stage, arrange themselves once more, in couples, in an equatorial plate. This time there is no splitting of the chromosomes. Round one member of each pair of chromosomes a fragment of the cell-substance aggregates, and the resulting little cell is extruded as a bud—the second polar body. The other members of the couples remain in the nucleus of what is now a mature ovum, furnished (like a mature spermatozoon) with only half the complement of chromosomes found in the body-cells of the animals concerned. Meanwhile the first polar body has divided into two miniature cells. There are thus produced out of the primary ovocyte, by division and subdivision, four cells, of which only one is viable, whilst the three others perish.

THREE-FOURTHS OF ALL OVA PERISH

B.—That seems most unthrifty. Why should so many fewer ova mature than might conceivably do so ?

A.—There is a sound biological reason for what occurs. Even though the number of theoretically possible ova is reduced to one-fourth, the survivors are left with more nutritive yelk for the embryo than if all four of the products of division and subdivision of the ovocyte had been of equal size and had all survived. Since, moreover, in every animal, many more rudimentary ova are formed than will ever mature, and since only a few of those which mature will be fertilised, the reduction in the number of potential ova that occurs during maturation does not in any way impair the prospects of the maintenance of the species. Of the 60,000 ova, more or less, laid down in a woman's ovary, only six on the average will be fertilised and successfully develop. The spermatozoa, on the other hand, which play no part in supplying food-stuff to the fertilised ovum, but serve merely to carry the paternal heredity factors, are produced in immense numbers and equipped with very active motility to ensure fertilisation. About 200 million spermatozoa are expelled in one ejaculation, and of this vast number only one (unless there is to be a multiple pregnancy) will reach its goal. We find throughout nature this extravagant expenditure of gametes or reproductive cells in order to ensure the preservation of the species.

NUMBER OF REPRODUCTIVE CELLS DEPENDS ON THE FACTOR OF DANGER

B.—Are these gametes, then, produced in such vast numbers by all animals ?

A.—The number of the spermatozoa is closely related to the difficulties which a spermatozoon will encounter in trying to reach an ovum. To take one instance, in many of the lower crustacea, which evacuate their spermatozoa in the immediate neighbourhood of the ova, so that fertilisation is almost what in the language of the turf is called a dead cert, the number of the spermatozoa hardly exceeds that of the ova. In these animals the spermatozoa, even when mature, retain most of the characteristics of ordinary cells and are nearly as large. The number of the ova is likewise proportional to the dangers they will encounter on their path to adulthood. The more careful the provision made for the safety of the brood, the more the production of ova declines. In oviparous (egg-laying) creatures, such as birds and reptiles, the eggs are few when the parent animals devote much attention to safeguarding them. Also when the egg contains a proportionally large yolk, development can proceed farther before the young has to quit the egg and is exposed to the vicissitudes involved in an independent search for food. The developmental stage at which a young bird, for example, pecks its way out of the shell is directly dependent upon the amount of nutriment stored up in the egg.

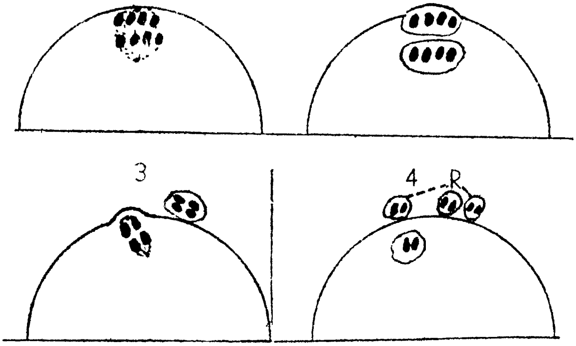

FIG. 48.—REDUCTION-DIVISION IN THE OVUM OF AN ANIMAL WHOSE BODY-CELLS FOUR CHROMOSOMES.

1, the chromosomes of the ovocyte have split longitudinally and have arranged themselves in an equatorial plate ; 2, first division (not a reduction-division). Round four of the chromosomes a small quantity of the cell-protoplasm has accreted, to form the first polar body, which is being extruded from the large ovum. 3, without a resting-stage, the nucleus of the ovum and that of the first polar body proceed to a new division, the real reduction-division. No longitudinal splitting of the chromosomes occurs, the four chromosomes in each nucleus ranging themselves in an equatorial plate without more ado. 4, division is complete, and (the second polar body having been extruded, and the first having undergone a reduction-division) has resulted in the formation of a mature ovum and of three polar bodies, each of the four cells having only two chromosomes in its nucleus.

THE BLACKBIRD AND THE SNIPE

B.—A striking illustration occurs to me. Blackbirds and snipe are much of a size, but a blackbird's egg is a good deal smaller than a snipe's. The result is that a blackbird hatches out as a callow nestling, a helpless creature, which has to be fed by its parents ; whereas a young snipe is well covered with down when it quits the egg, and is very soon able to run about on the search for food, under the mother-bird's supervision.

FERTILISATION

A.—Yes, a signal instance.—I think you have now learned enough about the preliminaries to understand the processes of fertilisation. These can, of course, be most easily studied when they occur in the water, outside of the bodies of the creatures to which the ova belong. Particularly favourable for examination are the ova of echinoderms (sea-urchins and the like). If, to a drop of water on a microscopic slide, you add the male and female gametes freshly procured from the reproductive glands of a sea-urchin, you will see numerous spermatozoa swimming briskly towards each ovum.

RECEPTIVE EMINENCE

As soon as the first spermatozoon draws near to and begins to perforate the tender gelatinous covering in which the ovum is enveloped, this latter extends a small protoplasmic process, the receptive eminence, or fertilisation cone, in the direction of the invader, and it is through this that the head and the shank (the nucleus and the centrosome) of the spermatozoon enter, while the tail drops off and is left outside. Almost simultaneously, the outermost plasma-layer of the

PREVENTION OF DUPLEX FERTILISATION

ovum condenses into a tough membrane, which proves an effective barrier to the entrance of other spermatozoa—a necessary precaution, for such multiple fertilisation would probably result in the production

CONTRIBUTION OF THE PATERNAL ORGANISM

of monsters. The paternal organism contributes the hereditary equipment borne by its chromosomes, and also the centrosome which presides over cell-division (or as it is called in the case of the fertilised ovum, segmentation)—for the centrosome of the egg-cell atrophies or at least remains inactive. (See Fig. 49.)

B.—What puzzles me is, how the spermatozoa find the ova.

GUIDANCE OF THE SPERMATOZOA TO THE OVA

A.—Presumably through the working of what are called chemotaxic influences, chemical lures emitted by the ovum—much as the smell of a bitch on heat attracts all the dogs of the neighbourhood. Ries believes that the mature ovum of a sea-urchin is surrounded by a sphere of soluble transparent substance, which forms what he calls the court of fertilisation. This substance, having been dissolved, diffuses through the water, and all spermatozoa that come within its range are supposed to be impelled to swim in the direction of stronger concentration. It can be shown for a fact that certain acids attract, certain others repel, spermatozoa. But there are other ways in which spermatozoa are guided towards ova. In a gentle current, spermatozoa always swim upstream. The Fallopian tubes are lined with ciliated epithelium, and the cilia wave towards the uterus, moving the discharged ovum (which is non-ciliated and inert, having no power of spontaneous movement) slowly on towards the womb. But

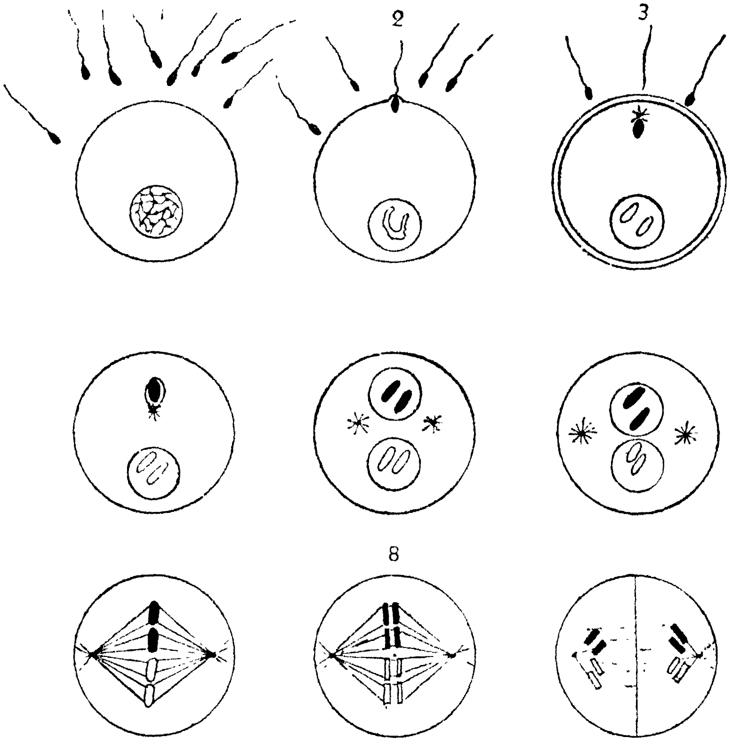

Fig. 49.—Fertilisation of the Ovum and its First Segmentation in an Animal whose Body-cells have Four Chromosomes.

1, mature ovum, being approached by a number of spermatozoa. The chromatin is still equably distributed in the nucleus ; 2, the ovum has stretched forth a receptive eminence (the fertilisation cone), which has been penetrated by the head of a spermatozoon. The chromatin of the nucleus has coalesced to form a convoluted thread. 3, the ovum has formed a stout membrane, which hinders the penetration of any more spermatozoa. Rays are issuing from the male centrosome, formed out of the shank of the spermatozoon. The chromatin of the nucleus has taken the form of two chromosomes. 4, the head (nucleus) of the spermatozoon has made a half-turn, so that now the centrosome points at the nucleus of the ovum, towards which the nucleus of the spermatozoon is moving. This nucleus is less consolidated than it was, and has surrounded itself with a nuclear membrane. 5, the spermatozoal centrosome has divided, and the two centrosomes thus formed are moving towards opposite poles of the cell. The chromatin of the spermatozoal nucleus (male pro-nucleus) has, like that of the oval nucleus (female pro-nucleus), now divided into two chromosomes. 6, the male pro-nucleus and the female pro-nucleus adjoin one another in the middle of the cell. 7, the nuclear membranes of both the pro-nuclei have disappeared, and the maternal and paternal chromosomes have arranged themselves in an equatorial plate enveloped in the spindle of rays proceeding from the two centrosomes ; 8, longitudinal splitting of the chromosomes ; 9, first segmentation of the fertilised ovum. Each of the daughter-cells has four chromosomes, two of paternal and two of maternal origin.

the tendency of the spermatozoa to swim upstream makes them move in the opposite direction, i.e. towards the descending ovum.

Speed of a Spermatozoon's Movement

B.—How quickly do spermatozoa cover the ground ?

A.—Human spermatozoa under the microscope can traverse a distance of 3 millimetres in a minute. Probably in the uterus they advance less quickly, and may take as long as three hours to get through the canal of the cervix from the external os (mouth) to the internal os, where the uterine cavity proper begins. Let us return however to our sea-urchin's spermatozoon whose head and shank

Nucleus of Ovum and Spermatozoon

have penetrated the outer wall of an ovum. Immediately thereafter, the head of the spermatozoon (male pro-nucleus), as if drawn by magnetic attraction, begins to move towards the female pro-nucleus produced by the above described reduction-division and the extrusion of the polar bodies. Though at first its point or "snout" was directed toward the female pro-nucleus, it makes a half turn, with the result that the shank, which represents the male centrosome, is between the two pro-nuclei. Round this centrosome the familiar radial pattern (aster) forms. By the absorption of fluid from the ovum-plasm, the chromatin in the male pro-nucleus becomes thinner in consistency, and when at length, in the middle of the cell, it encounters the female pro-nucleus, it has come to look like an ordinary nucleus containing separate chromosomes (but always, you must bear in mind, only half as many as the body-cells of the animal from which

Reconstitution of the Full Equipment of Chromosomes

it has been derived). The male pro-nucleus and the female pro-nucleus coalesce to form a new joint nucleus, now equipped with the ordinary number of chromosomes—the segmentation nucleus. At least that is what usually happens, but there are exceptions. Fertilisation is now completed. End of Act I. Segmentation of the ovum, Act II, can begin.

B.—What happens to the centrosome?

First Segmentation of the Ovum

A.—Meanwhile the centrosome, just as in the prelude to an ordinary cell-division, has separated into two parts, each of which, with its court of attendant radiations, has moved to one of the poles of the cell, and the radiations that pass centralwards form the customary spindle. Between them lie the chromosomes of the male and female pro-nuclei which have formed the segmentation nucleus. The chromosomes of paternal and maternal origin arrange themselves across the middle of the spindle as an equatorial plate. Thus the segmentation-nucleus

Half the Hereditary Equipment comes from the Father

or the equatorial plate, has half of its chromosomes, the bearers of heredity factors, provided by the father, and half by the mother. Segmentation, the first cell-division of the fertilised ovum, proceeds in the ordinary way, all the chromosomes splitting longitudinally, the severed halves moving (drawn by the spindle rays) toward the respective poles of the cell to form daughter-nuclei, while the furrow which is to divide the cell-body into two makes its appearance round the equator. Thus is produced a two-celled embryo, and all metazoa or multicellular animals pass through this stage (unless produced asexually, in ways presently to be described). Fertilisation and the first segmentation of the fertilised ovum are shown diagrammatically in Fig. 49.

B.—Then the nuclei of the two cells produced by this first segmentation contain, each of them, like the fertilised ovum, the normal equipment of chromosomes, half of which have originated from the nucleus of the matured ovum, and half of them from the nucleus of the spermatozoon?

A.—I see you have grasped the idea. These two cells grow, and in turn divide and subdivide, forming an embryo of 4, 8, 16, 32, etc., cells, until, by many hundreds of thousands of successive divisions, all the cells of the adult organism have come into being. Since at each and every division the chromosomes are handed down in like manner from generation to generation, it comes to pass in the end that all the cells of the body have the same complement of chromosomes in their nuclei as had the nucleus of the fertilised ovum. Since the male pro-nucleus and the female pro-nucleus each contributes 24 chromosomes to the human ovum, every one of our body-cells contains 48 chromosomes, half of them being descendants of the chromosomes in the head of the spermatozoon, and half of them descendants of the chromosomes in the nucleus of the ovum before fertilisation but after the reduction-division. In other words, through all the successive generations alike of the cells and of the individuals these cells build up, the chromosomes maintain their number and retain their individuality. Potentially, therefore, every fertilised ovum has packed away within it all the heredity factors of the coming generations. Since the male pro-nucleus and the female pro-nucleus always (with one exception to be considered later) contribute the same number of chromosomes to the nucleus of the fertilised ovum, the body-cells of every living creature produced by an act of sexual union must contain an even number of chromosomes.

CHROMOSOMES RETAIN THEIR INDIVIDUALITY THROUGH THE GENERATIONS

CHROMATIN IS THE CARRIER OF HEREDITY

B.—This sedulously equable allotment of the chromatin unquestionably makes one think that it must be the carrier of heredity.

A.—The matter is so important that I will once more run over the grounds which justify such a belief. One of them, as you have just said, is the sedulously equable distribution of chromatin during the process of nuclear division. There is no other among the cell-contents which is dealt out so scrupulously. Further, the reduction in the number of chromosomes by one half when the maturation of the ovum takes place and when the spermatozoa are being formed, indicates that chromatin must be of peculiar importance to our vital processes. If any doubt were left, it would be removed by what occurs during fertilisation. Since the gametes or reproductive cells develop into new organisms in which all the characters of the progenitors recur, they must, somehow or other, convey the heredity factors requisite to this reproduction ; and since, as we learn from experiments in hybridisation (the union of distinct but kindred species, such as the horse and the ass), the offspring inherit parental characters from the father and the mother in approximately equal proportions, the exceedingly minute spermatozoon must be of as much importance as the ovum in the conveyance of heredity factors. Now the only thing in which the ovum and the spermatozoon—so different in other respects—are identical is in the number and composition of their chromosomes. Finally, the marked individuality and independence of the chromosomes speak strongly for their being the carriers of heredity. This assumption is strikingly confirmed by the results of laborious breeding experiments, of which you will hear when we come to consider the laws of heredity.

B.—Do ovum and spermatozoon respectively contain all the heredity factors requisite for the production of a complete organism, or does each of the gametes contribute only one half of an equipment of heredity factors ? In the former case, an ovum should be theoretically capable of developing into a normal individual even in the absence of fertilisation.

A.—This is practically, as well as theoretically, possible, as is shown by numerous instances of what is called parthenogenesis—asexual or virginal reproduction. Surely you must be familiar with the summer generations of aphides or plant-lice, procreated by unfertilised females at a time when there are no males on hand. This is a natural process. But ova which normally need fertilisation will sometimes develop into new organisms though fertilisation has not taken place, or can be artificially induced to do so. When working at the Marine Zoological Station in Naples I noticed that sea-urchin's ova to which no spermatozoa had been supplied would sometimes, after a few days (as if tired of waiting), begin to undergo segmentation. True, this process was soon arrested, and the embryos perished at an early stage. But if the concentration of the sea-water was moderately increased, the requisite stimulus was supplied, and these unfertilised ova developed into normal larvæ (plutei). Delage even succeeded in rearing full-grown sea-urchins from such parthenogenetic larvæ. Frogs' ova, when pricked with a glass needle, will, though unfertilised, undergo segmentation, developing into tadpoles and at length into frogs. This proves that the mature but unfertilised ovum contains a full set of the heredity factors, or, as Morgan calls them, the genes, needed for the production of a complete organism.

Development without Fertilisation

Artificial Parthenogenesis

B.—I suppose nothing of the kind is possible to a spermatozoon, since it has lost its cell-body.

Spermatozoa can likewise develop "parthenogenetically"

A.—You are mistaken. A spermatozoon can develop into an organism on its own, if you provide it with the cell-body it has lost.

B.—How can that be done?

A.—If you put the sea-water containing mature ova of the sea-urchin into a bottle and shake the bottle violently, the ova break up into nucleated and non-nucleated fragments. Should you now transfer some of the non-nucleated fragments into sea-water containing sea-urchin's spermatozoa, the spermatozoa will penetrate the fragments just as if they were normal ova. You might expect such an act of "fertilisation" to be fruitless. By no means, for the ovum-plasma thus equipped with a nucleus derived from the head of a spermatozoon will undergo a seemingly normal segmentation. Boveri and other investigators have grown normal sea-urchin larvæ from such embryos to which the female pro-nucleus was lacking. The plutei thus produced were distinguishable from normal congeners only by their small size (the fragment of ovum fitted with a male pro-nucleus having less nutritive material than an undamaged ovum fertilised in the usual way). This shows that the head of a spermatozoon has a complete set of genes, and could, theoretically, develop into a complete organism.

ALL HEREDITY FACTORS ARE PRESENT TWICE OVER

B.—In other words, the fertilised ovum contains a complete double set of heredity factors?

A.—Certainly. But let us go back to the reduction-division. The ova and spermatozoa arising from the reduction-division of the ovocytes and spermatocytes are not identical in respect of the heredity factors or genes they contain, for the paternal and maternal genes still associated in the mother-cells are, in the reduction-division, very variously assorted to the daughter-cells. Thus it may happen that a spermatozoon or an ovum may receive only the paternal or only the maternal chromosomes.

B.—I don't understand why.

IN THE REDUCTION-DIVISION THE MATERNAL AND THE PATERNAL HEREDITY FACTORS SEPARATE

A.—Let us suppose the members of a species to have in their body-cells eight chromosomes, half of them derived from the father and half of them from the mother; and that the chromosomes containing the same paternal and maternal genes look exactly alike. In illustration we will assume that in the reproductive mother-cells there are four distinct pairs of chromosomes: one pair of rods; one pair of loops; one pair of spheres; and one pair of cubes. To simplify, we will denote the chromosomes of paternal origin by the letters A B C D, and those of maternal origin by the letters a b c d.

PERMUTATIONS AND COMBINATIONS

To make the possible permutations and combinations more comprehensible to you, I will use a somewhat crude example. You have eight apples: two calvilles, two rennets, two Blenheim oranges, and two Americans. But there is a little difference between the members of each pair; e.g., one of the calvilles is a trifle larger than the other, and the same with the rest. Now you are asked to assort these apples by fours so that in each assortment there will be no two apples of the same variety. Experiment will soon show you that there are eight possible arrangements, any one of which is equally probable if the selection is left to chance. The same thing happens in the distribution of four pairs of maternal and paternal chromosomes in the reduction-division whereby the matured reproductive cells are formed. The extreme case would be a complete separation of maternal and paternal heredity factors, so that one of the daughter-cells will contain chromosomes ABCD, and the other chromosomes abcd. But I will make you a complete list of the other possible combinations in such a division, all seven being equally probable :

1. ABCd and abcD
2. ABDc and abdC
3. ACDb and acdB
4. Abcd and aBCD
5. ABcd and abCD
6. AbcD and aBCd
7. aBcD and AbCd

If chance decides the assortment of these maternal and paternal chromosomes, then, in an animal whose cells had 8 chromosomes, there will, according to the calculus of probability, arise in each of the sexes 16 kinds of reproductive cells which will differ in the assignment of maternal and paternal elements to their respective nuclei. Hybridisation experiments show that this is actually so. In the act of fertilisation, when the paternal and the maternal heredity factors are brought together again in the fertilised ovum, 16 × 16 combinations are possible. Let us suppose that the female pro-

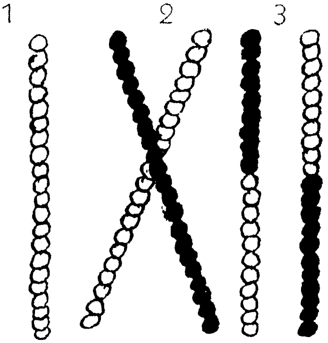

FIG. 50.—DIAGRAMMATIC REPRESENTATION OF PAIRED CHROMOSOMES, CARRYING PARTICULAR HEREDITY FACTORS (GENES) LIKE BEADS UPON A STRING.

Paternal genes shown black, maternal genes in outline.
1, the pair has the paternal and maternal elements completely separated ; 2, the paired chromosomes have crossed one another X-fashion ; 3, the members of the pair have separated, but have exchanged halves, so that the upper half of one contains maternal and the lower half paternal genes, and conversely.

nucleus contains the chromosomes aBcD, and the male pro-nucleus the chromosomes abcD, then in the nucleus of the fertilised ovum there will be, for the heredity factor 1, two chromosomes of maternal origin aa; for the heredity factor 2, one paternal and one maternal, Bb; for the heredity factor 3, again two maternal chromosomes, cc; and for the heredity factor 4, two paternal chromosomes DD—and the combination of paternal and maternal qualities in the developing child will be according.

Since there are numerous species which have many more than eight chromosomes, the number of possible combinations is enormously multiplied. Nor by that alone, for a chromosome does not merely carry the heredity factor for one character or quality, but those for a great many; and since the genes that transmit these characters or qualities can be interchanged between the paired chromosomes, the possible combinations of maternal and paternal elements in the offspring increases to an almost inconceivable number.

B.—What bearing has all this on the doctrine of heredity?

A.—I will answer your question in due course, when we come to consider the laws of heredity. You shall not lure me from my main thread again to-night.

TWELFTH EVENING

DEVELOPMENT OF AN ORGANISM

The Ovum of Amphioxus

A.—Your zeal for information has led us off the track. Still, since we have discussed fertilisation out of its turn, I will to-day, starting from the fertilised ovum of the lancelet (Amphioxus lanceolatus) give you a broad outline of the way in which the adult animal develops. The first embryological phase is a rapid segmentation and resegmentation of the egg-cell. The numerous cells thus produced, draw their nutriment from the yelk (a variant of the word " yolk ", but the latter is best reserved for the great mass of yelk in a bird's egg) in the ovum, unless, like the embryos of mammals, they are nourished from the maternal circulation. In the earliest phases of development, the embryonic cells are all very much alike ; but by degrees they undergo differentiation, to fit them for their respective tasks. Groups of similar cells form tissues, and out of these the rudiments of organs are built up.

B.—Why do you choose as example the ovum of a creature so little known ?

A.—For two cogent reasons. First of all, because embryological processes are exceptionally easy to follow in these creatures. Secondly, because the lancelet is the lowest known type of vertebrate ; and I think you will be especially interested to study the elements of embryology in a member of that division of the animal kingdom to which we ourselves belong. As you see in these sketches, through the formation of a meridional furrow the egg-cell first divides into two cells, and then, by the subdivision of each of these, into four cells which remain closely approximated. (See Fig. 51.)

B.—What are the little circles drawn above the egg-cell ?

Polar Bodies

A.—The three abortive ova extruded by the ovocyte. You learned of them as polar bodies.

B.—Yes, I remember, but I don't know why they are called that.

A.—Because, in many cases, their position gives us a clue to the orientation of the ovum. We can regard the ovum as having a principal axis, one end of which, the one at which the polar bodies

Animal and Vegetable Poles

are extruded, is, because of subsequent developmental processes, known as the animal pole. The opposite pole, for reasons which you will learn in due course, is called the vegetative pole. Now let us follow the process of division a stage farther. By the formation of an equatorial furrow, the four cells are, almost simultaneously, divided into eight. Then arise 16, 32, and still more numerous cells, which (since they absorb little if any nutriment) are naturally smaller at each generation. They do not constitute a solid mass, for a space appears in the middle of them, so that they are arranged as a sac formed of a single layer of cells, and spherical in shape. This sac is called the blastula. (It is shown in cross-section in Fig. 52, A.)

THE BLASTULA

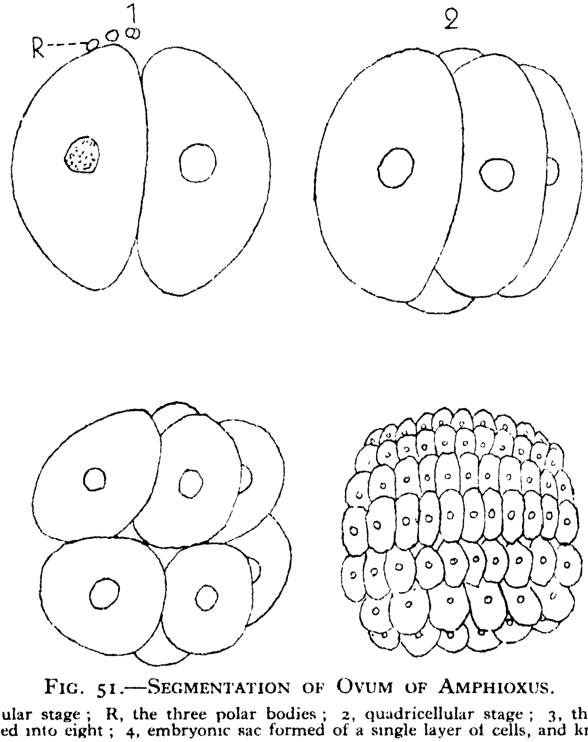

FIG. 51.—SEGMENTATION OF OVUM OF AMPHIOXUS.

1, bicellular stage; R, the three polar bodies; 2, quadricellular stage; 3, the four cells have divided into eight; 4, embryonic sac formed of a single layer of cells, and known as the blastula.

B.—I see that already at this early stage the cells have begun to differentiate. The upper half of the blastula is made up of smaller cells than the lower half.

A.—The explanation of this difference is found in the structure of the amphioxus' ovum, whose cell-body is not homogeneous. The main part of the thick nutritive substance or yelk collects at the lower, the vegetative pole, whereas at the upper, the animal pole, there predominates a thin protoplasm, termed here the formative yelk.

DISTRIBUTION OF THE YELK

DELAYED SEGMENTATION

Of course the nutritive yelk divides less easily than the formative, with the result that fewer but larger cells arise at the vegetative than at the animal pole. In a sea-urchin's egg, which has the yelk equably distributed, segmentation at this phase exhibits no such differentiation.—The division of the cells that form the blastula continuing,

FOLDING AND DIFFERENTIATION

there now ensues a process of folding or invagination, the formation of the rudiments of the organs being brought about, not only by the differentiation of cells, but also by the production of folds and by the stricturing-off of particular groups of cells. Picture to yourself a rubber ball with a hole in it, so that the air it contains can be expelled. If you press one side of the ball, you will drive that side in ; it will be invaginated or intussuscepted into the other side, with the result that a stemless goblet having a double wall will be produced. Now,

THE GOBLET-SHAPED EMBRYO (GASTRULA)

no one pits the blastula by pressing it with the finger-tip, but the vegetative pole is invaginated in consequence of the more rapid division and subdivision of the cells at the other pole ; and there consequently arises a goblet-shaped embryo, the gastrula, whose wall is composed of a double layer of cells. Still, no more than

A PURELY MECHANICAL EXPLANATION IS INADEQUATE

the tissue-changes in the cells can be fully explained as due to the working of exclusively chemico-physical laws, but only if we invoke the idea of an independent collaboration on the part of the living protoplasm, can this process of invagination or intussusception of half of the wall of the gastrula into the other half be accounted for in exclusively mechanical terms. Here, too, we see a purposefulness which laughs at any other explanation than that of purposefulness. Hitherto, at any rate !—The aperture which leads into the interior of the gastrula is known as the primitive mouth (blastopore) ; and the cavity into which it leads is called the primitive gut (archenteron).

THE GERMINAL LAYERS

The gastrula, as already explained, originates as two layers of cells, one layer directed towards the outer world and the other towards the archenteron. The former is called the outer skin or ectoderm ; the latter, the inner skin or endoderm. (See Fig. 52.) All multicellular animals pass through such a gastrula stage in early embryonic life, though often in a modified form. Indeed, we know an animal,

HYDRA

the fresh-water polyp (hydra), which never advances beyond the gastrula stage. For in hydra the body-wall consists of only two cell-layers investing a sack-like cavity with a blind end. In hydra, however, certain secondary differentiations have occurred in the cells both of the ectoderm and of the endoderm in order to fit the creature for

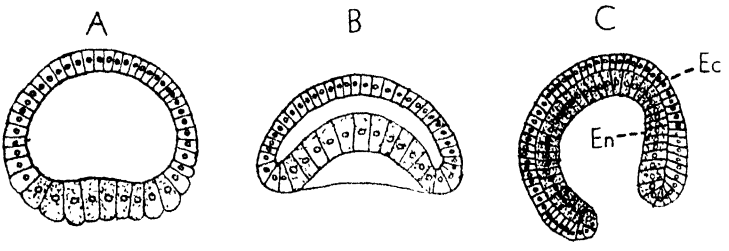

FIG. 52.—GASTRULATION IN AMPHIOXUS.

A, cross-section through the blastula shown in Fig. 51, 4; B, invagination has begun; C, gastrulation is complete. B and C are also in cross-section. Ec, outer germinal layer, or ectoderm; En, inner germinal layer, or endoderm.

its life as an independent adult. But in amphioxus development proceeds farther. The primitive mouth, which ultimately becomes

RUDIMENTS OF THE ORGANS ARE FORMED

occluded, is in amphioxus at the posterior end of the body, the opposite pole being the front end. The outer germinal layer gets folded in longitudinally, so that a gutter-like furrow is formed. On either side of this furrow, the cells of the outer germinal layer project in a ridge, the proliferating cells ultimately meeting and adhering in the middle line, with the result that what were originally ectoderm cells now lie beneath them in the interior of the body. Simultaneously, the cells of the various parts of the body of the embryo undergo increasing differentiation. (See Fig. 53.)

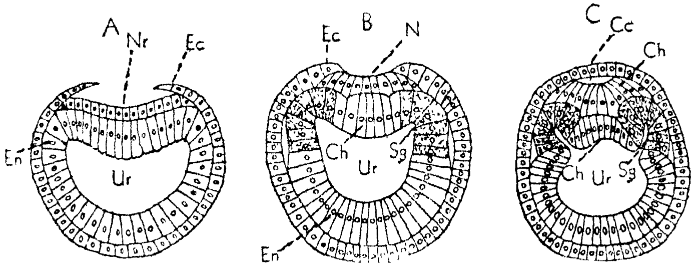

FIG. 53.—ORIGIN OF THE SPINAL CORD, THE NOTOCHORD (CHORDA DORSALIS), THE PRIMITIVE GUT, AND THE MIDDLE GERMINAL LAYER.

A, the outer germinal layer (Ec) has furrowed, as a preliminary to the formation of the neural canal (Nr); the inner germinal layer (En) has closed to form the primitive gut. B, the part of the wall of the primitive gut that lies underneath the neural furrow has become differentiated to form the notochord or chorda dorsalis (Ch); the parts of the wall of the primitive gut lying to right and left of the notochord are forming the primitive segments (Sg). C, the folds of ectoderm have grown together behind the neural furrow to enclose the neural canal; Ur, primitive gut; Sg, primitive segments.

B.—Can we already learn what organs will proceed from these different cell-layers?

A.—Yes. The furrow that forms in the ectoderm is nothing

FORMATION OF THE CENTRAL NERVOUS SYSTEM

other than the rudiment of the central nervous system. I have already explained that the folds which grow up along either side of this furrow (the neural furrow) meet over it and join so as to transform it into a canal (the neural canal). The cellular wall of this canal is the rudiment of the spinal cord. Simultaneously, folds form in the endoderm lining the interior of the primitive gut. The cells that lie along the dorsal side of the gut just in front of the neural canal separate themselves longitudinally from the wall of the gut,

NOTOCHORD AND VERTEBRAL COLUMN

becoming segregated and differentiated to form a massive longitudinal string, the rudiment of the chorda dorsalis or notochord. In primitive fishes this structure persists throughout life as a cartilaginous rod. In higher vertebrates, on the other hand, by subsequent segmentation and ossification, the notochord is transformed into the vertebral column consisting of the vertebral bodies with their arches, spines, lateral processes, etc. The vertebral arches enclose and protect the spinal cord ; the processes are for the articulation of the ribs, the attachment of muscles, etc. (Refer back to Fig. 27, p. 106.) The next step in development is for the endoderm of the gut-wall lying on either side of the notochord to be differentiated into a series of diverticula, whose mouths close, so that the wall of the gut becomes continuous once more. These serial shut-off saccules form the middle germinal layer (mesoderm). In the further development of

ORIGIN OF THE ORGANS

the vertebrates, the muscular system, the pericardium, the diaphragm, the peritoneum, the excretory organs, and the reproductive organs, are what the mesoderm chiefly gives rise to. From the rudiments of the aforesaid organs are produced by proliferation and segregation of cells : the connective tissues, the cartilages, the bones, the tendons, the blood-vessels, the lymphatic system (glands and vessels), the spleen, the bone-marrow, and the involuntary muscles (including the heart). The ectoderm chiefly contributes the outer layers of the skin (the epidermis), the nervous system, and the sense-organs. From the endoderm come the lining membrane of the alimentary canal and the digestive glands.

A PERSISTENT GASTRULA

B.—If the hydra is an animal that has persisted at the gastrula stage, one may suppose that its ectoderm and endoderm, respectively, have to fulfil for this primitive organism similar functions as do in higher animals the organs that have developed out of these layers.

A.—That is so. The outer layer of cells in hydra serves, like the epidermis in higher animals, to clothe the body and to protect it from the noxious influences of the outer world. Also, in the freshwater polyp, some of the ectoderm cells develop into simple sense-organs. The endoderm, on the other hand, lines the intestinal canal (or, rather, sac), and furnishes the digestive secretions. Of course, in hydra, all this organisation is most elementary. Since the little polyp has no middle germinal layer, but has to make certain movements in order to carry out its vital processes, at the plane where the ectoderm and the endoderm are in apposition they produce longitudinal and transverse muscular fibrils. With the aid of these, the animal can lengthen or shorten its body and modify the position of its tentacles. We need not occupy ourselves further with this special case ; but I should like to know what inferences supporting the doctrine of descent you can draw from the embryological facts I have just been recounting.

B.—It seems to me they all tend to show that during embryonic life the higher animals pass through phases which were terminal for their remote ancestors, as the gastrula stage is terminal for hydra.

THE " FUNDAMENTAL BIOGENETIC LAW "

A.—You hit the bull's-eye, and have formulated a principle which is dominant in embryology, the biogenetic law, as it is called, which tells us that as an embryo every animal passes through phases which, as you put it, were terminal in this or that remote ancestor of the species. Haeckel phrased it thus : " Ontology is a recapitulation of phylogeny ". An epitomised recapitulation, however, for

DEVIATIONS

many ancestral phases are shortened, and some are even obliterated. Not only do the fully grown individuals of a species adapt themselves to particular environmental conditions by developing new characters ; but likewise in the course of the millenniums their immature phases from the fertilised ovum upward are exposed to a changing environment, and have to make new adaptations. Phylogenetic conclusions drawn from embryological study must, therefore, be sharply criticised. To give one example, in the larvæ of the

PREHENSILE LIP OF THE DRAGON-FLY LARVA

dragon-fly the lower lip has been transformed into a long pair of pincers, and there have been various other adaptations to the creature's predatory aqueous life, but we must not therefore infer that the dragon-fly's ancestors, if they lived in the water, had such characters.

NOT A LAW, BUT A RULE

The so-called biogenetic law is not a law in the strict sense of the term, for to a natural law there can be no exceptions ; it is better to speak of it as a rule, which finds abundant confirmation, and from which many notable conclusions can be drawn. Haeckel himself insisted that in ontogenesis (the embryonic development of the individual) two processes are intertwined. First of all there is

PALINGENESIS AND KAINOGENESIS

epitomised ancestral development (palingenesis), thanks to which, during individual embryology, there is a cursory and incomplete recapitulation of certain ancestral stages. This palingenesis is interfered with and overwritten by kainogenesis, inasmuch as the embryo or larva acquires characters which did not exist in the ancestry. A full repetition of all ancestral phases during individual development from ovum to adult would unduly protract the process. The inevitable upshot is that many of the genealogical details are summarised or suppressed.

Suppression of Genealogical Details

The serial order in which the vestiges appear may likewise be modified, so that certain organs are formed sooner or later than the ancestral history might lead us to expect. In most cases these deviations can easily be explained as adaptations to changes in the conditions environing the embryo. You can judge for yourself.

The Cell as the Starting-Point of Development

The fact that all multicellular organisms begin their lives as unicellular organisms (the fertilised ova), is regarded by naturalists as a proof that phylogenetically the one-cell stage was the starting-point for all higher animals and plants. But it has been pertinently remarked that the ova of a cockchafer, those of a lion, and those of a human being must differ as widely in their structure as do the respective adults ; for, however much the conditions may vary, they develop respectively into cockchafers, lions, and human beings. This is indisputable, and yet the objection lacks validity. Only on the supposition that the oval stage is an ancestral stage, can we account for the fact that all multicellular organisms traverse it, and that there is such amazing uniformity in the ostensible structure of the ova in all classes of animals. Even those ova that have a very disparate appearance, have the same fundamental type. The divergencies are due to secondary adaptations.

The Mammalian Ovum and the Bird's Egg

A mammalian ovum, which develops inside the mother's body and is nourished from the maternal circulation, does not need the huge yolk and the hard shell of a bird's egg, the former to supply the isolated embryo with nutriment, and the latter to protect it against damage.

B.—How can you prove that this is the cause of the differences ? You cannot make a bird bring living young into the world, nor induce a mammal to lay eggs.

A.—Your first statement is correct, but there are egg-laying mammals. Have you forgotten the monotremes, or cloacate egg-laying mammals ? The eggs laid by the duck-mole and the porcupine ant-eater have large yolks and a rigid shell, in these important respects being like birds' eggs. Nevertheless the ova of the most diversified forms of animals are not merely much alike in structure, but the embryology of all multicellular animals proceeds along the same lines down to the gastrula stage. Lest I should lay myself open to the reproach of putting a gloss upon the matter, I must explain once more that the above-described development of amphioxus represents only the simplest type. But in the ova of creatures belonging to widely separated branches of the animal kingdom, so far as they lack an abundant store of nutritive material, the same equable segmentation is observable. In other cases, however, owing to the accumu lation of great quantities of nutriment and to variations in its arrangement, there are marked peculiarities in gastrulation, which can only be revealed by the most thorough-going investigation.

Modifications in Cell-Division

In many species, embryonic development follows strange paths, developmental stages being intercalated that are necessary for the embryo or the larva, but producing structures and organs for which the adult has no use. These structural changes entail marked modifications in the processes of cell-division.

Metamorphosis

The direct line of development gives place to a metamorphosis which is often associated with far-reaching reversions and transformations. Think of the extraordinary differences between a caterpillar and an adult butterfly or imago. The organs adapted for larval life cannot develop directly into those needed by the winged insect.

Phagocytes destroy Larval Organs

The necessary changes go on in the chrysalis, during what is called the pupal stage. In this resting-stage certain white blood-corpuscles, those of the kind known as phagocytes or eating-cells, invade the larval organs, and destroy their cell-substance. But at the same time a process of reconstruction is going on.

Imaginal Discs

The destruction is necessary to provide room and building materials for the organs of the imago. Not all the cell-substance of the larval organs is eaten away. Certain small plates, the imaginal discs, consisting of undifferentiated cells, escape destruction; and by these embryonic cells, to the accompaniment of the gradual suppression of the larval organs, the metamorphosis into the imago is achieved. (See Fig. 54.) Let us go back, however, to the consideration of more normal embryological processes, in which the transition from ovum to adult takes place gradually and steadily, and is not masked by sudden, stormy reversions or metamorphoses. Even in the later embryonic phases of members of the various great families of the animal kingdom, we note so striking a resemblance in the matter of origin and further development of the respective organic systems, that the idea of derivation from a common root forces itself on our minds as the only valid explanation of the similarity.

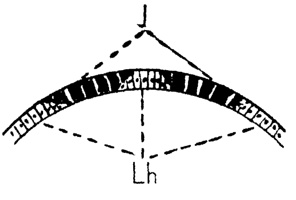

Fig. 54.—New-formation of the Skin of the Imago from the Imaginal Discs (J) with the Suppression of the Old Larval Skin (Lh) in the Pupa of a Fly. (After Kowalewski.)

Origin of the Central Nervous System

Thus in all vertebrates the central nervous system arises in the same way as in amphioxus. In the outermost cell-stratum a furrow forms along

Rudiment of the Brain

the mid-line of the back of the embryo, the edges of this furrow grow inwards to join so that they enclose what becomes the neural canal, the surrounding cells forming the central nervous system—at first only the spinal cord. In amphioxus the nervous system remains permanently in this primitive condition, the lumen of the neural canal being the same throughout, except that at the anterior end a bulbous dilatation appears, and in other vertebrates this develops into the brain. It becomes proportionally larger as we rise in the animal scale, subdividing into the three primary cerebral vesicles, which grow more complex by degrees, until at length we have a brain of the type found in all vertebrates ranging from the higher fishes to man, and consisting of cerebrum (with two hemispheres), cerebellum, mid-brain or mesencephalon, hind-brain or epencephalon (pons Varolii and crura cerebri), and the medulla oblongata. Despite this similarity of ground-plan, there are marked differences in the appearance of the brain in various classes of vertebrates—differences that depend on diversities in the comparative size and development of the five cerebral vesicles. Concomitantly with increasing intelligence, we note also increasing divergence in size and structure as between cerebrum and cerebellum, both being proportionally larger in the higher vertebrata than in the lower. In birds already, but still more in mammals and especially in man, cerebrum and cerebellum overshadow all other parts of the brain.

B.—Am I to understand you that in all vertebrates the formation of the brain begins as a bladder-like expansion of the neural canal, which gradually subdivides, first into three and then into five vesicles, the ancestral stages of development being always traversed so far as this organ is concerned ?

Phylogenetic Stages reappear

Von Baer's Misadventure

A.—A good summary ! Peculiarly effective support to the doctrine of descent is supplied by the fact that the younger the embryos of different classes of animals, the more striking their resemblance. As Leche insists, " if you are shown a canine embryo at a very early stage, you will find it impossible to say whether the embryo is indeed that of a dog or that of some vertebrate much lower in the scale. Not until later do the characters appear that enable you to assign it to one of the higher classes. Still later manifest themselves the characteristics of the beast of prey, and at length those of the canidæ ; though not usually until after birth will the appearances be sufficiently distinctive to tell us whether we have to do with a dog, a wolf, a fox, or a jackal ". The story of a little misadventure that happened to K. E. von Baer, the founder of comparative embryology, will serve to illustrate this statement. Let me give it you in his own words : " I have two embryos preserved in spirit. By an oversight, the bottles were left unlabelled, and now I cannot tell what they are !

They may be lizards, or little birds, or very immature mammals, so close is the resemblance, in early embryonic life, between the formation of head and trunk in these various classes of the animal kingdom. The limbs have not yet been formed; but even if they had been, they would not, at the outset, give me a clue; for the legs of lizards and of mammals, the wings and the legs of birds, and even the hands and the feet of human beings, are all built up on the same ground-plan." Of course these embryos, however much outwardly alike,

Overlaying of Phylogenetic Characters

are not identical, for each of them bears within its cells, in addition to the phylogenetic characters they have in common, the subsequently gained heritable characters peculiar to each, destined with further development to become predominant and to overlay the more general characters they share. The embryological development and the

Blood-Vascular System and Respiratory Organs

perfectionment of the blood-vascular system and the respiratory organs in vertebrates give like plain indications of derivation of all vertebrates from a common stock. As you know, these two organic systems are closely interconnected, and influence one another reciprocally. When vertebrates leave the water, and gill-breathing is replaced by lung-breathing, the blood-vascular system must adapt itself to the new conditions and must undergo appropriate changes. Since in

Gills and Lungs

fishes it is through the gills that the absorption of oxygen by, and the discharge of carbonic acid from, the blood is effected, there is in these animals a special system of bloodvessels leading to and from the gills. In most fishes there develop four pairs of gill-arteries, which break up into capillaries in the gills. Having traversed these organs, the capillaries join again to form veins. In the larvæ of amphibia, which live in the water, and, like fishes, breathe by means of gills, similar gill-arteries and gill-veins are found. But many amphibia, our frogs for instance, wholly or partly quit the water when they grow up, and become air-breathing land-dwellers. Their gills, being of no more use to them, atrophy, and so do the now superfluous bloodvessels. One pair of the gill-arteries disappears altogether; another pair, becoming pulmonary arteries, carries blood to the lungs. (See Fig. 55.) Other details concerning the fate of the gill blood-supply lie outside our present scope. The important thing is that even the higher and very highest vertebrata, which never lead independent lives in the water and never breathe by means of gills, have during early embryonic life a gill circulatory system like that of fishes

The Fish's Heart in the Human Embryo

and amphibia. You can actually trace the ancestral developmental stages in the human heart. At first it is a fish's heart, with one auricle, one ventricle, and a sinus venosus; then comes the amphibian stage, in which there are two auricles; at length in the ventricle

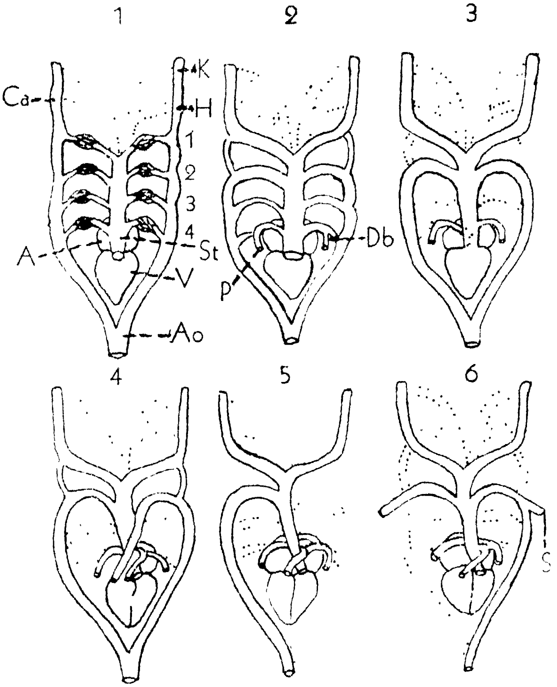

FIG. 55.—DIAGRAM SHOWING THE GRADUAL TRANSFORMATION OF THE GILL CIRCULATION INTO THE PULMONARY CIRCULATION.

1, from a fish; 2, from a salamander; 3, from a frog; 4, from a lizard; 5, from a bird; 6, from a mammal. The suppressed blood-vessels are shown by dotted lines. V, ventricles of the heart; A, auricles; Ao, main arterial trunk (aorta); K and H, the two anterior embryonic aortic arches, the first to be suppressed; 1, 2, 3, 4, the four posterior aortic arches; Ca, carotid artery; P, pulmonary artery; Db, ductus arteriosus or Botallo's duct; S, subclavian artery.

there forms a septum, incomplete, as in the crocodile; until at last, when the right and left ventricles are entirely shut off from one another, we have the mammalian four-chambered heart.

B.—Is it true that the human embryo in the early days of intra-uterine life, has gill-clefts like those of a fish?

GILL-CLEFTS

A.—With certain reservations, yes. In all vertebrate embryos, the human fœtus included, there appear very early, on both sides of the neck, transverse parallel furrows, separated by arches of skin. The number of these furrows varies in different classes of animals. At first they are all covered by a membrane, tensed from arch to arch. In the lower vertebrates this membrane subsequently disappears, to leave open clefts between the exterior of the body and the pharynx. They are called pharyngeal clefts or gill-clefts, and the arches of skin that separate them, being ultimately provided with a cartilaginous or bony supporting framework, are the pharyngeal arches or gill-arches. In the human fœtus the aforesaid membrane is not absorbed, so the gill-clefts are not opened up, but their rudiments are certainly present.

B.—Why do not the gill-clefts open in the human fœtus?

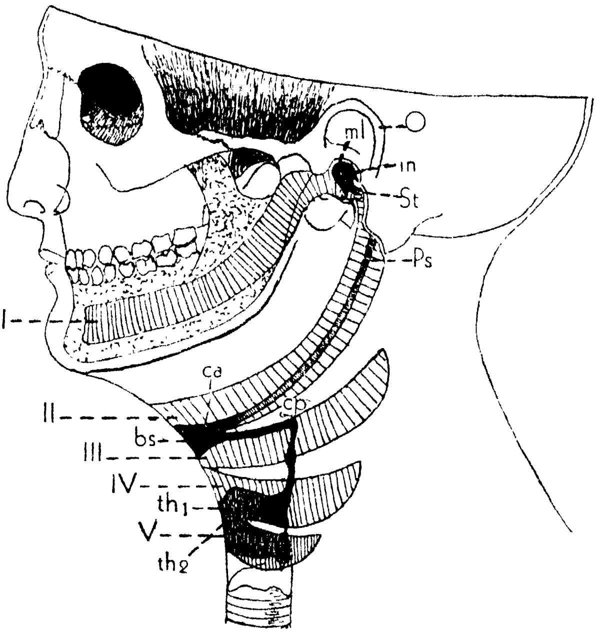

Fig. 56.—Vestiges of the Gill-arches in Man. (After Wiedersheim.)

I to V, first to fifth primordial gill-arches. Out of the first arch proceed the auditory ossicles, the malleus (*m*) and the incus (*in*). To disclose them, the ear-drum has been removed. St, stapes; O, external ear. From the second gill-arch derive the styloid process of the temporal bone (**Ps**), the lesser cornua (*ca*), and part of the body (*bs*) of the hyoid bone. From the third gill-arch develop most of the body (*bs*) of the hyoid bone, and the greater cornua (*cp*) of the same. From the fourth gill-arch derives the upper part of the thyroid cartilage of the larynx (th_1), and from the fifth the lower part of the same (th_2)

Tenacious Clinging to Ancestral Traits

A.—Perhaps we can only explain their appearance at all as a tenacious clinging to ancestral traits. Anyhow, since the human young never breathe by means of gills, the sketchy development of them is soon arrested, and a reversionary process ensues. The gill furrows are filled in, and the gill-arches disappear long before birth. It will interest you still more to learn that the laying-down of this gill apparatus is not completely futile, for, by suitable changes, parts of it take on new functions. The anterior gill-cleft, for instance, greatly modified, persists throughout life.

Change of Function

B.—But there is nothing that resembles a gill-cleft to be seen even in a new-born child.

EAR AND GILL-CLEFTS

A.—You cannot recognise as much from what you see in the infant, but embryologically a great part of our hearing apparatus derives from the first gill-cleft and the first gill-arch. Are you acquainted with the structure of the human auditory organs ?

B.—Not intimately.

A.—Well, I will give you a brief account of them. From the external ear, the external auditory meatus leads to the membrana tympani or ear-drum, which blocks the passage into the tympanic cavity. A continuation of the canal leads through the Eustachian tube into the pharynx. In the tympanic cavity are the three auditory ossicles, which conduct the vibrations produced in the ear-drum by air-waves across to the cochlea whose cavity is lined with special-sense cells that are the receivers for the auditory nerve. Now, the external auditory meatus, the drum-cavity, and the Eustachian tube represent the first gill-slit ; while the malleus and the incus are rudiments of the first gill-arch. (See Figs. 56 and 57.) But the other gill-arches do not disappear without leaving traces. From parts of the second and third gill-arches are derived the lesser cornua and the body of the hyoid bone ; and from the fourth and fifth, are derived the thyroid cartilage of the larynx, and probably the arytenoid cartilages whose changes in position modify the tension of the vocal cords. All rudimentary organs are weak spots, especially prone to morbid change. Thus in the human embryo, through an arrest of development, a vestige of the second gill-cleft may persist as what is known as a cervical fistula leading from the pharynx to the exterior of the neck. Such arrests of development are, unfortunately, rather frequent. For instance, in the human embryo the upper jawbones and the frontal process are primarily distinct, and only coalesce after a while. Should this coalescence fail to occur, we get the hideous malformation known as hare-lip, a cleft which in extreme cases may extend up into the orbit.

CERVICAL FISTULA AND HARE-LIP

B.—The foregoing embryological data seem to me far more convincing than even " the record of the rocks ", and to show conclusively that the human race must have developed from lower creatures, obviously fish-like.

CIRCUMSTANTIAL EVIDENCE

A.—Still, there is one thing you must never forget. Fossils are direct evidence ; whereas embryological data furnish only circumstantial evidence, even though it be circumstantial evidence that can hardly bear any other interpretation.—Another indication of our derivation from marine ancestors is supplied by the fact that the salts dissolved in human blood-serum are those found in sea-water, and in the same proportions, but in a weaker solution.

BLOOD-SERUM AND SEA-WATER

B.—No doubt it is because of this peculiar composition of the blood that in cases of severe hæmorrhage the lost blood can be successfully replaced by the injection of diluted sea-water?

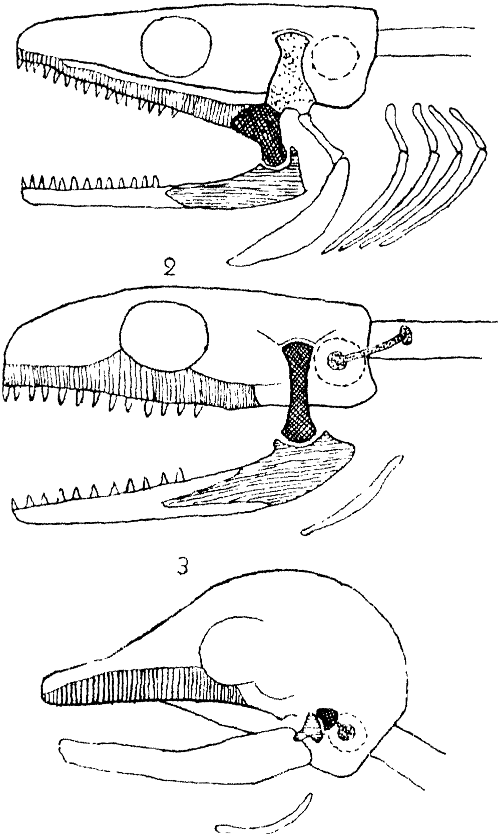

FIG. 57.—TRANSFORMATION OF THE BONES WHICH ORIGINALLY FORMED PART OF THE ARTICULATION OF THE JAW INTO AUDITORY OSSICLES. (After STECHER.)

1, skull of a fish; 2, that of a reptile; 3, that of a mammal. Cross-striation shows the malleus; hatching, the incus, punctiform marking, the stapes.

A.—Yes, sterilised sea-water is really better for "transfusion" than "normal salt-solution", i.e. an artificial solution of sodium chloride having the same density as blood-serum. In many other animals we see even more clearly than in man, how tenaciously they cling to organs which can be "called up", as it were, for renewed but different service under changed conditions of existence. In the

THE MOUNTAIN SALAMANDER

Swiss mountains you have probably seen the black mountain salamander (Salamander atra). Unlike the familiar salamander of our part of the world, the mountain salamander does not lay its eggs in water, but is viviparous, producing young that are air-breathers from the time they come into the world. In embryonic life, however, they have well-formed, bushy gills, of which, in normal circumstances, they will make no use. But these gills are able to function as such. If you cut the gilled larvæ out of the maternal oviducts, and put them in an aquarium-tank, the young live cheerfully as water-breathers. Obviously, then, the mountain salamander had ancestors which used to bring forth young that lived in water; and the retention of the embryos until the metamorphosis into air-breathers has taken place, must be a fairly late acquisition in phylogenetic life. The reason for the change is not far to seek. In the high mountains, gently flowing streams with quiet pools where ova laid in water can develop are seldom found, so the Alpine salamanders were forced to become viviparous.

SEXUALLY MATURE LARVÆ

B.—Then the conditions that obtain among mountain salamanders are precisely opposite to those which obtain in the case of the axolotl, which, as you told me a few evenings back, persists in the larval gill-breathing stage, becoming sexually mature as a larva. Is the axolotl an example of arrest at an early phase of evolution, or of reversion to a mode of life which the species had for a time transcended?

A.—Opinions vary. Weismann held that the ancestors of the axolotl in the Mexican lakes must have been land-dwelling salamanders in the Diluvial epoch. When the forests were cleared and the atmosphere became drier, they would have become extinct unless a reversion to the fish-salamander form had enabled them to become permanent water-dwellers once more.—But we must resume our main line of advance. If you look at an earthworm, a bee, a fish, a tortoise, a fowl, a horse, a human being, what strikes you as the most salient characteristic common to them all?

B.—That they have an anterior and a posterior end, a back and a belly, a right side and a left.

BILATERAL SYMMETRY

A.—Yes, especially the last. All these animals show a strict bilateral symmetry, as it is called; this meaning that when you cut them into two halves from head to tail, each half resembles the other seen in a mirror. Especially the extremities and the most important sense-organs are, in the higher animals, equably distributed to the right and left sides of the body. Furthermore the sense-organs are chiefly at the front end of the body, so that when (as in the articulata and vertebrata) there is a sharply distinguishable head, the organs of special sense are found exclusively there. Obviously for freely moving

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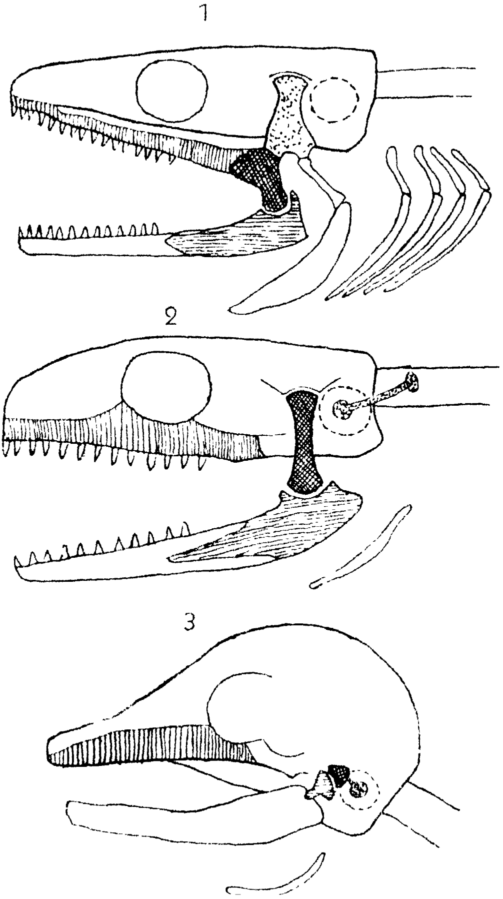

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SHEDDING OF TEETH

ancestors of the right-whales used to shed their teeth, for above the rudiments of the milk-teeth, is a second row, the rudiments of the permanent teeth, which likewise fail to develop. Similar conditions obtain among the tortoises, which are toothless, and have the jaws beset with horny plates, made of the same kind of substance as a bird's beak. But the embryo tortoise has rudiments of teeth.

THE TESTIMONY OF THE INVERTEBRATES

B.—Hitherto you have spoken only of vertebrates. Does not the embryology of invertebrates supply evidence in favour of the doctrine of evolution ?

A.—It supplies remarkably strong evidence. In the case of invertebrates, above all, we find numerous embryological data whose only plausible explanation is along the lines of the theory of descent.

B.—I should be very glad to have some information upon this point, since I am less well acquainted with invertebrate than with vertebrate animals.

LEGS OF ECHINODERMS

A.—I cannot doubt that in an aquarium you must have watched echinodermata : the variously coloured five-rayed starfish, the prickly, globular sea-urchins, the delicate feather-stars or sea-lilies (crinoidea), the blastoidea, polothuridea, etc. They differ so much in structure and general aspect, that you would hardly believe them to be closely akin. But these differences are only external, and intimate study shows astounding resemblances in their ground-plan and their embryology. Especially is this true of their " legs " or locomotive organs, which contrast so markedly with the locomotive organs of all other animals.

B.—In what way are their legs so peculiar ?

A.—They are not legs at all, in the ordinary sense of that term. If you have ever watched a starfish climbing up the glass front of its tank, you must have noticed the longitudinal furrows that run along the under surface of the five rays, and from the middle of which numerous translucent little tubes project. As you look, you see the foremost of these tubes elongate themselves, and cling to the glass with the aid of the tiny suckers in which they end. When the starfish has thus got a grip, the tubes shorten, and slowly draw the animal upward. Then the ray is projected again, and the process repeated, so that, slowly but surely, the starfish can climb up the smooth glass. The most surprising characteristic of these " ambulacral feet " is their mode of operation. The feet are the extensions

WATER-VASCULAR SYSTEM OR HYDRAULIC APPARATUS OF STARFISH

of a comprehensive system of tubes within the body of the starfish. It begins at a sieve-like structure known as the madreporic plate, situated on the back of the animal. Through the pores in this plate, water makes its way into the water-vascular system. From the madreporic plate a fine tube, the stone-canal, leads to a circular canal, the ring-canal, surrounding the gullet. The ring-canal has lateral diverticula, little ampullæ, which serve for the storage of water. There also radiate from the ring-canal into the five arms long radial canals to which on either side are attached the ambulacral feet. Each of these protrusile tubes is, at its proximal end, likewise furnished with a water reservoir or ampulla. When the animal is quiescent, the suckers are scarcely noticeable externally; but as soon as the starfish wants to move, water is discharged into the ambulacral feet by a spontaneous contraction of the appropriate ampullæ. The feet are extruded, and the suckers cling to whatever is handy. When the internal pressure relaxes, the water flows back into the ampullæ, the radial canal, and the ring-canal; the ambulacral feet shorten, and draw the starfish towards any object to which they may have attached themselves. (See Fig. 59.) A water-vascular system modelled more or less after this pattern exists in all echinoderms, that of the sea-urchins resembling that of the starfish most closely. In the elongated holothuridea (sea-slugs, sea-cucumbers, trepangs, etc.), only three of the five ambulacral series are provided with suckers and serve as organs of locomotion; for the "feet" on the upper side of the animal are pointed, and have become tactile organs. Degradation of the ambulacral system has advanced yet farther in the crinoidea (hair-stars and sea-lilies) which, when they have not adopted a sedentary life, can climb easily with the aid of their thin arms, so that they have no use for ambulacral feet. All the other organs of echinoderms manifest a corresponding similarity of fundamental plan.

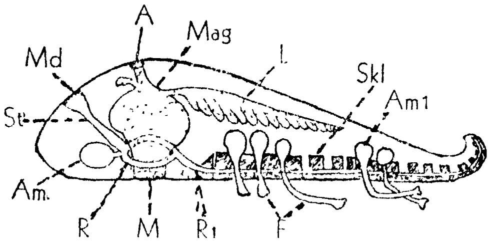

FIG. 59.—VERTICAL SECTION THROUGH THE CENTRAL PART AND ONE OF THE RAYS OF A STARFISH. (Diagrammatic.) (After PLATE.)

A, anus; M, mouth; Md, madreporic plate; Am, ampulla; St, stone-canal; R, ring-canal; R 1, radial canal; F, ambulacral feet; Am 1, ampulla of a foot; Mag, stomach; L, liver; Skl, parts of skeleton.

Radial Structure of Echinoderms

B.—Earlier this evening you said that a radial structure in contradistinction to a bilateral was characteristic of animals that had adopted a sedentary life. But the echinoderms you have been describing move about freely. This seems inconsistent.

A.—Once more a matter of ancestry! The echinoderms are a very old class of the animal kingdom. Their earliest representatives, the sea-lilies (crinoidea) of the Cambrian, closely akin to our hair-stars, were fixed to one spot ; and we are justjfied in assuming that all the echinoderms spring from sedentary forefathers. Even so, the sedentary mode of life and the radial structure of crinoidea were secondary acquirements. The larval development of all the echinoderms shows that they have developed from a freely mobile, bilateral, vermian stock, and that their becoming attached to one spot and assuming a radial structure came later. Still later, some of them resumed a more active existence, but the radial structure has persisted, more or less strongly marked, even in the freely moving types.

B.—What leads to the supposition that these aberrant creatures are akin to the worms ?

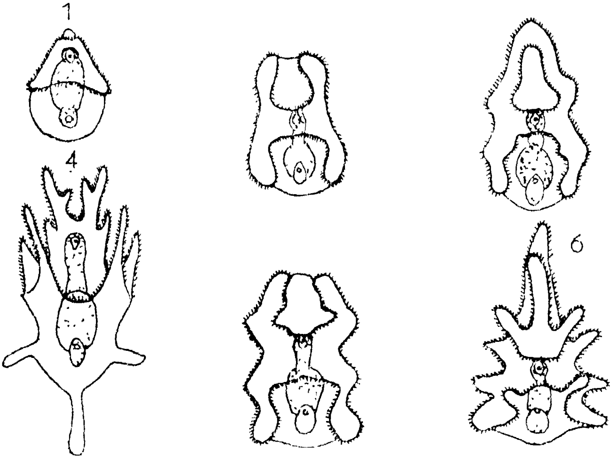

FIG. 60.—LARVÆ OF ECHINODERMS.

1, primordial type of larva through which all forms pass ; 2 and 5, bipinnaria larva of the starfish ; 4, pluteus larva of the sea-urchin ; 3 and 6, larvæ of sea-cucumbers. The tripartite intestine is distinguished by punctiform marking ; the fringe of cilia by hatching.

A.—Embryology, again. Echinoderms pass through a very complicated metamorphosis. From the ova develop larvæ which differ markedly from the adult forms in their bilateral symmetry and in the gelatinous constitution of their bodies. Fig. 60 shows the larvæ of the different orders. All these larvæ proceed from a common type, which has a tripartite intestine, and a fringe of cilia surrounding the mouth—these cilia serving as locomotive organs, for the larvæ are free-swimming. The differences that appear in the respective larvæ during later phases of development consist chiefly in a lengthening of the fringe of cilia, which remains single in pluteus and auricularia, whereas in bipinnaria a part of the body surrounded by a special crown of cilia becomes marked off in front of the mouth.

B.—How does this larva develop into an adult ?

A.—Let us first ask what the ovum of an echinoderm looks like,

WHY HAVE ECHINODERMS LARVÆ ?

why it should first develop into a larva, and then into a starfish or a sea-urchin of an utterly different type. Most echinoderms discharge their reproductive cells into the sea, where the spermatozoa have to find the ova. Of course many ova perish, without ever being fertilised. The risks of this are so great, that enormous quantities of ova have to be produced. If we open the calcareous exoskeleton of a sexually mature female sea-urchin, we find that the distended ovaries with their countless ova occupy the greater part of the interior. These ova, even after maturation, are extremely minute, and contain only a small quantity of nutritive yelk, sufficient for the first few segmentations. Then the tiny larvæ have to fend for themselves. The transformation and development of the ovum into a little free-swimming larva equipped with a fringe of cilia and with a tripartite intestine, occupies no more than a few hours. In that brief time, the cumbrous adult echinoderms can traverse only a short distance. Their habitat would, consequently, soon become over-populated were not the free-swimming larvæ carried long stretches away by their own exertions and by oceanic currents, to colonise new areas. The metamorphosis of larva into adult is achieved by the lateral budding of a little starfish or sea-urchin, as the case may be, while the greater part of the larval body withers away.

B.—Still, it does not seem to me that the existence of these bilaterally symmetrical larvæ supplies adequate proof that the echinoderms must have sprung from bilaterally symmetrical parents. May we not be concerned here, as in the case of dragon-fly larvæ, with a kainogenetic deviation intercalated into individual development ? Perhaps the larvæ became bisymmetrical in adaptation to changing conditions of existence ?

A.—Though it is fairly certain that the forbears of the echinoderms did not closely resemble these larvæ, the existence of the larvæ has

TRANSITIONAL FORMS

an important bearing on the theory of descent, since they form a bridge to the vermian stock. The larval form of the peculiar worm

THE TORNARIA LARVA OF BALANOGLOSSUS

balanoglossus, the tornaria larva, as it is called, is so like an echinoderm larva that it can easily be mistaken for one. This leads us to infer that, long, long ago, echinoderms branched off from wormlike, i.e. bilaterally symmetrical, ancestors, and then evolved in a way peculiar to themselves. You might object, of course, that the larvæ of echinoderms and those of balanoglossus, without being related, acquired a similar form through being exposed to similar conditions. But peculiarities in the organisation of the adults of both kinds of animals bear witness to their common genealogy. In balanoglossus the proboscis, which can be erected through the imbibition of water, subserves the purposes of locomotion, and this remarkable organ develops out of a diverticulum from the larval intestinal canal just as does the water-vascular system of echinoderms.

B.—Are there other instances of such links between different classes of animals ?

A.—Yes, the tornaria larva (see Fig. 61) is of great importance in this connexion. But before I go into that matter, I should like to finish with the echinoderms. The embryology of the hair-stars differs notably from that of the other echinoderms. The first distinctive phase of the development of their ova is the production of barrel-shaped ova, which are free-swimming for a time, but soon cling to sea-weeds or stones by means of a little groove which forms on the ventral surface. The fringe of cilia atrophies, and a long stalk strengthened by calcareous segments sprouts, at the free end of which stalk the little hair-star gradually develops. Herewith balanoglossus has reached what is known as the pentacrinus stage. After a time the little head severs itself from the stalk, and grows into a sexually mature hair-star. Now this pentacrinus stage has a striking resemblance to the sea-lilies (crinoidea) of the Cambrian epoch. As I think I told you before, the crinoidea were very widely diffused in early geological ages. There are many palæozoic deposits several metres thick which are entirely composed of the joints of their stalks and of other remnants of their calcareous skeletons. With few exceptions, these sea-lilies were attached by long stalks, and thus closely resembled the immature form of our hair-stars. Herein we find another confirmation of the fundamental biogenetic law, for it is manifest that the hair-stars have only become freely motile organisms at a comparatively recent date in geological history. In the deep sea, where the conditions of life are practically immutable, stalked hair-stars (stalked even when adult) have persisted on into our own times.

PENTACRINUS STAGE

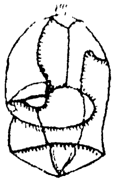

FIG. 61. — TORNARIA LARVA OF THE MARINE WORM BALANOGLOSSUS. (After METCHNIKOFF.)

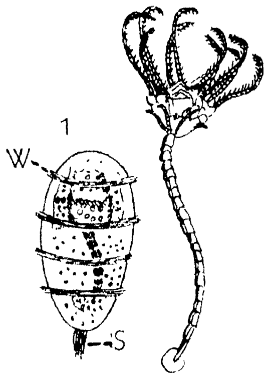

FIG. 62.—THE TWO LARVAL FORMS OF A HAIR-STAR.

1, Free-swimming barrel-shaped larva ; 2, attached pentacrinus stage. W, coronal of cilia. S, tuft of cilia

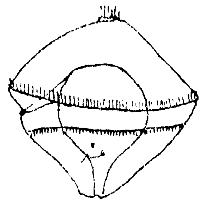

FIG. 63. — TROCHOPHORA LARVA OF A MARINE ANNELID.

B.—In that case the pentacrinus stage must be an indication of earlier genealogical forms, whereas the barrel-shaped larva is presumably a kainogenetic formation?

TROCHOPHORA

A.—Yes. I now go back to your previous question. In the embryology of the marine annelids (ringed worms), we come across a free-swimming larva, the trochophora, which is almost spherical in shape, has rows of cilia, and a tripartite intestine. Out of this the adult worm develops by metamorphosis and a process of elongation. This statement applies to the marine annelids, let me repeat. Freshwater annelids, on the other hand, develop directly as such, no longer passing through a free-swimming larval stage. I expressly say " no longer ", for careful study of their embryos shows plain indications of a trochophora form, from which we infer that at one time they, too, traversed a free-swimming larval stage. Furthermore, larvæ resembling trochophora (Fig. 63) are found also in molluscs, spoonworms (zephyrea), and moss-animalcules (bryozoa or polyzoa). The close similarity of their larval forms indicates that these very different classes of animals had a common ancestry. You must avoid however figuring it out as if trochophora were the repetition of a surpassed ancestral stage of adult animal. What I mean is that trochophora represents the joint larval stage of the ancestral stocks.

ROTIFERS

Now to consider another order of the animal kingdom, that of the wheel-animalcules or rotifers. In the flooded rice-fields of the Philippines, Semper discovered a rotifer which was so like trochophora in structure that he called it Trochosphæra æquatorialis. A good many other rotifers, however, strongly resemble trochophora, so that many observers incline to consider rotifers as organisms which have undergone an arrest of development at the trochophora stage, and are sexually mature larvæ. What you have learned of the Mexican axolotl has already taught you that larvæ can remain in such a condition of arrested development, in which, nonetheless, they become sexually mature. The scientific name for such a condition is neoteny.

Also in animals whose adult types are extraordinarily different from those we have been considering, in the crustacea, there are larval forms (the nauplius stage and the zoea stage) so much like the trochophora, etc., as to indicate a genealogical kinship. But I will not overburden your mind with details. To-morrow we shall devote ourselves to the study of rudimentary and vestigial organs, which give unambiguous testimony in favour of the theory of evolution.

THIRTEENTH EVENING

DEFECTS IN ORGANISATION

DEFECTS IN CONSTRUCTION

A.—Up till now our conversations have been a eulogy of the purposefulness of organic nature. But this purposefulness is no more than relative. Defects and maladjustments force themselves on our attention from time to time. " If my assistant were to bring me a physical apparatus as badly constructed as the human eye, I should give the fellow the sack," declared Helmholtz. The existence of rudimentary or vestigial organs is the most striking illustration that there are limits to the purposefulness of nature.

RUDIMENTARY AND VESTIGIAL ORGANS

B.—What precisely do these terms mean ; are they synonymous ; and how do you know whether an organ is rudimentary or vestigial ?

A.—In this connexion, they are synonymous ; but the term vestigial is to be preferred, for rudimentary has two widely contrasted meanings. A " rudiment " may either be the imperfect (" rude ") beginning of what will or may develop into something better (the swimming bladder of a mudfish being the rudiment of a future lung), or else it may be the vestige of something which has served a useful purpose, but is now merely a trace of past glories. " Vestigial " is therefore the better term, but the synonymous misuse of " rudimentary " is so ingrained, that I cannot promise to avoid it altogether. In Latin, " vestigium " meant a footprint. A vestigial organ, then, is one which has no present function, but " lags superfluous on the stage ", whereas in the congeners of the organism that possesses it it has, or in the ancestors of that organism it had, an adequate and useful task. The significance of these functionless organs only becomes comprehensible through a study of the history of the species. We have to do with the tenacious reconstitution, generation after generation, of some part of the body which was originally important to the life-processes, but which changed conditions of existence have deprived of its value. The genes for the production of this organ are so firmly anchored in the germ-plasm, that they persist in each act of fertilisation, and compel the reconstruction of the vestigial organ by the cells of the appropriate part. But since there is no longer a fulcrum on which the lever of natural selection can rest in order to perfect or at any rate preserve the organ in question, it slowly undergoes degenerative changes, becoming smaller or less satisfactorily developed. (For the latter reason it is called " rudimentary", being a "rude", a rough-hewn reproduction of the organ in its prime.) But as I told you before, this degeneration may be arrested by the functionless part adopting a new function, which gives it a fresh developmental impetus, in adaptation to changing conditions.

B.—I suppose you are thinking of the pineal gland, which, out of the rudiment of the now functionless third and unpaired vertebrate eye, has developed into an important endocrine gland?

"Calf" and "Kalb"

A.—Yes, the instance is a good one. But to make the nature of a vestigial structure clearer to you, I will quote a vivid analogy from Richard Hesse: "In the English word for 'Kalb', namely 'calf', the 'l' is silent; but the silent letter is retained in the written form, and we know that the words 'calf' and 'Kalb' sprang from a common Teutonic root, in which, doubtless, the 'l' was functional, was pronounced. This 'l' is, in fact, a vestigial organ in the word 'calf', and would, by its preservation in spelling, lead us to infer that the ancestors of the English sounded it, even though we had not the kindred German word to guide us in our supposition." Furthermore, not particular organs only, but complicated developmental states and

Vestigial Habits

various habits may become rudimentary. An example of a vestigial habit is furnished by the kicking-backward and scratching-backward movements which our domestic dogs make with their hind-legs after voiding their excrement, even if it be upon a town pavement. In unconscious reproduction of the ways of remote ancestors, these movements, which have now become unmeaning and atrophic, are repeated. The domestic cat is more conservative, and still, when garden mould is not available, carefully buries its fæces. The turning round and round of dogs before they lie down is unquestionably a vestige of the practice of treading out a comfortable nest among fallen leaves. But the movements are utterly purposeless when carried out on a parquet floor.

The Nauplius Larva of Crustaceans

B.—What was in your mind when you said that a complicated developmental state might become rudimentary?

A.—I will illustrate my words by an example. Yesterday evening I mentioned that, as a stage in the life-history of many crustaceans, a peculiar form of larva, known as a nauplius, develops. It is a small, lively, unsegmented creature, which swims briskly hither and thither, propelling itself through the water with the aid of three pairs of limbs. (See Fig. 64.) The widely diversified forms of crustaceans develop out of these larvæ by a more or less complicated metamorphosis. Now, in many of the lower crustaceans, and conspicuously in the water-fleas (daphnias) so much used for feeding fishes, the free-swimming nauplius stage is lacking. Young daphnias are hatched out fully formed from the ova in the incubating chamber beneath the mother's shell; but before hatching they have, in the egg, passed through a nauplius stage precisely resembling that of the free-swimming naupliuses of other kinds of crustaceans. Thus water-fleas are splendid examples of the clinging of ontogenesis to a long-past form of phylogenesis, although a changed mode of life has made this developmental phase superfluous. No doubt you know that growing crustacean larvæ and crustaceans that have surpassed the larval form slough their shells several times. Were this not done, the rigid chitinous exoskeleton would be an insuperable obstacle to enlargement. Thus, in the literal sense of the phrase, we can from time to time see a young crustacean "jump out of its skin". But, before this, there has formed beneath the rigid, old shell, a new, soft, and elastic one. Almost immediately after emerging from what has become a prison, the animal's body increases remarkably in size, so that one finds it difficult to understand how the creature could have had room to live in the cast shell. Gradually the new shell hardens, and there can be no further growth until the next sloughing takes place. Now I am going to tell you something that will astonish you. The unhatched nauplius of a water-flea sloughs its shell within the egg, which seems a futile performance, since the shell of the egg prevents any increase in size. This is a "vestigial practice" which clearly shows that the ancestors of daphnia produced free-swimming nauplius larvæ.

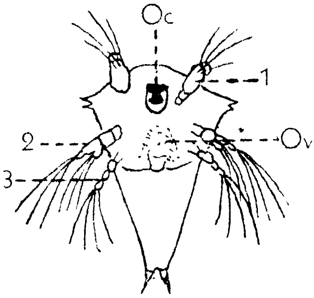

Fig. 64.—Nauplius Larva.

1 to 3, the three pairs of limbs, Oc, eye; Ov, ovary.

PARTHENOGENESIS

SUMMER AND WINTER EGGS

If you are not yet convinced, I have more ammunition in my wallet, and will fire another shot. First I must tell you about a peculiarity in the reproductive history of the daphnia of our own part of the world. In spring and summer you can find only female water-fleas, which procreate parthenogenetically. Their unfertilised eggs have comparatively thin shells, and the daphnias that emerge from them are invariably of the female sex. In autumn, however, when the water begins to cool, from some of these summer-eggs males hatch out, smaller than the females. The numerous parthenogenetic generations, which provided for a rapid increase, are succeeded, in the course of the annual rhythm, by a two-sexed generation, fitted for sexual procreation. Like the unfertilised summer-eggs, the fertilised winter-eggs are harboured for a time in the before-mentioned maternal incubating-chamber. Here they are coated with a tough chitinous shell, the chitin being secreted by special maternal glands. When the mother-daphnia sloughs her shell for the last time, the winter-eggs remain in the cast shell under cover of a peculiarly strong part of it, called the ephippium. They pass the cold season in the mud, safeguarded by this ephippium and their own thick, chitinous shells. With the general awakening of nature to life, in the spring season, the winter-eggs develop into the first summer brood of parthenogenetic females. Thus daphnias exhibit an alternation of generations, a number of parthenogenetic generations being, at the appropriate time, succeeded by a sexual generation. Now, in the Teglersee and certain other inland waters, there is a small crustacean about one centimetre long, another of the daphniadæ, called Leptodora hyalina because its refractive index is approximately the same as that of clear glass and pure water. If I were to hand you a glass of water containing a number of these creatures, you would find it hard to see them, for they wear, so to say, a cap of invisibility. You would only distinguish tiny brownish points, moving backward. This invisibility protects them from their enemies, and assists them to approach their prey unobserved. Of course the full stomach is not rendered invisible by the magic cap, and the brown points you see moving through the water are thus accounted for. Leptodora, too, lays summer-eggs and winter-eggs. In the summer-eggs, the young go through the nauplius-stage before hatching, just as do the young of daphnia ; but the winter-eggs hatch out into free-swimming nauplius larvæ. The reason for this difference is that the winter-eggs of leptodora, laid prematurely, do not contain enough nutritive material to provide for the long hibernation and the larval phases before hatching. The young would perish of inanition if they were not born as larvæ able to fend for themselves. You could hardly have a more convincing proof of the view I have been inculcating. It may be that leptodora is on the way towards that complete suppression of the free-swimming nauplius phase which has already been achieved by daphnia ; or it may be that the suppression had been effected, and that then, for reasons still obscure (but just hinted at), the production of free-swimming nauplius larvæ by the winter-eggs was revived.

Alternation of Generations

Leptodora

The Cap of Invisibility

B.—You said that when an organ became functionless, the lever of natural selection no longer had a fulcrum. I could understand that, if the organ concerned no longer developed. But since the rudiments of this organ are part of the hereditary equipment, surely it must continue to be formed just as of old ? I don't see why it should atrophy.

Lamarckian and Darwinian Explanations of Arrested Development

A.—This difficulty of yours will come up for consideration in connexion with the fairly detailed discussion of the various theories of evolution which will be more appropriate towards the close of our conversations. Just now, a brief answer must suffice you. The Lamarckians would say: " According to our experience and observation, use strengthens an organ, and non-use weakens it; consequently, if the non-use is persistent, it atrophies or is suppressed." But the matter is not so simple as that. It is quite true that a fully developed organ is weakened by non-use; but it does not follow from this, that the resulting weakness will injure the relevant genes in the reproductive cells of the individual concerned. The Lamarckian theory stands or falls according as it can be shown that acquired characters are or are not inherited. There has not as yet been recorded any indisputable example of the hereditary transmission of a character acquired during the individual's lifetime.—Now for the Darwinian standpoint. A Darwinist would say: " If an organ is to improve without ceasing, or merely to maintain such a state of excellence as it has already achieved, there must be, in the struggle for existence, a persistent selection of those individuals in which the organ is best developed. In fact, excellence of the organ must be one of the conditions of preferential survival." The varying excellence (or size) of the different organs of our body depends mainly upon corresponding differences in the respective genes. Since a functionless organ is useless, and indeed directly harmful (inasmuch as it " crowds " the other organs and robs them of part of their nutriment), selection in the struggle for existence ceases to promote the development of such organs, and their absence or atrophy becomes a condition of preferential survival. If, as we now suppose, a poorer development of an organ depends upon a poorer development of the relevant gene or genes, there will be a better chance of survival for those individuals in which the genes in question are below par. Should such a process continue for a long time, the disappearance of the organ in the course of a sufficient number of generations would result from natural selection. Of course I have put the matter somewhat crudely, to make the ideas easier for you to grasp. Nor must you forget that, according to the theory of evolution, we have, in the course of hundreds of millions of years, traversed countless evolutionary phases. Each of these phases is characterised by adaptation to special conditions of existence. When changes took place in climate or other environmental conditions, many of the adaptations that had occurred were unsuitable to or superfluous in the next evolutionary phase. Had all the adaptations made since the beginning of things until now remained as part of our hereditary equipment, instead of undergoing gradual atrophy, we should still have, in addition to our lungs, a functionless set of gills, which, with a number of other useless organs, we should have to grow and trail about with us, so that long since we should have ceased to have either room or formative material for the acquisition of new organs. This difficulty would, one must suppose, have brought the evolutionary process to an arrest.

B.—No doubt you will discuss the question more elaborately by and by. What I should be glad of now is to have fuller details concerning vestigial organs.

The Cæcum

A.—The most notorious among such organs is the human cæcum with its vermiform appendix. The small intestine enters the large by a T-shaped junction, so that the first part of the ascending colon (large intestine) forms a blind chamber. Attached to this chamber, the cæcum, and opening into it, is a short blind tube, of the average

Vermiform Appendix

diameter of a crow-quill, ill-famed because of its liability to dangerous inflammations. In vegetarian mammals, such as the rabbit, the cæcum is an imposing structure, and important digestive processes take place in it ; but in carnivores it is much shorter, and may be absent. In man, likewise, the cæcum is very short, and plays no more than a subsidiary part in the absorption of nutriment. But if the cæcum itself is vestigial or on the way to become so, still more does this statement apply to the vermiform appendix, of sinister reputation, and, so far as we know, absolutely functionless. It is true that Aschoff and Albrecht were disposed to believe that the appendix may have an endocrine significance, but it cannot be said that they proved their thesis. The extraordinary variations in the length of the appendix (ranging in man from 10 in. to a mere derision) run counter to any such supposition. Nor does operative removal of this structure ever lead to the onset of carency symptoms (symptoms resulting from the lack of some important substance which ought to be present in the diet or supplied by an endocrine gland—the symptoms that follow castration, removal of the thyroid, etc., are carency symptoms ; so are those of such diseases as rickets and beri-beri, due to a lack of certain vitamins). It is characteristic of most vestigial organs that their rudiments are laid down after the usual manner in early embryonic life, but that their development is soon arrested, and that in many cases they undergo more or less complete atrophy. In man, the cæcum and the vermiform appendix arise together as a diverticulum of the large intestine, a diverticulum which is at first of equal calibre throughout ; but soon the extremity of this diverticulum lags behind in its growth, so that in the end it becomes a trifling appendage to the cæcum into which it opens. (See Fig. 65.) Nor does it always " open ", for the researches of Ribbert have shown that often enough its lumen is completely obstructed. In 4% of the children whose bodies he examined on the post-mortem table, the tube was impervious ; in persons of 30, the percentage of obliterations had risen to 25 ; and in persons of 80, to nearly 60. There is some hope, therefore, that our descendants will be freed from this undesirable heritage of a lower-animal past.

B.—Has man any other vestigial organs ?

A.—Plenty ! Both in the human embryo and in adult men and women we find many organs and parts of organs which have become functionless or atrophic. Among such atrophic organs may be

Mammary Glands

mentioned the mammary glands of the male. But the mere reduction of the number of these glands to one pair is itself the outcome of atrophic processes, as is shown by the fact that supernumerary

SUPERNUMERARY NIPPLES

nipples are by no means rare in women and in men. Examining 100,000 Badenese recruits, Ammon and von Bardeleben found vestiges of supernumerary mammæ in 14,000. Many papillated structures on the front of the chest or abdomen, regarded by laymen

ANNE BOLEYN

as moles, are really supernumerary nipples. A famous historical character affected with polymastia (as it is technically termed) was the ill-fated Anne Boleyn, second wife of King Henry VIII. The

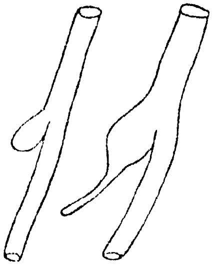

FIG. 65.—DIAGRAM SHOWING THE DEVELOPMENT OF THE CÆCUM IN THE HUMAN EMBRYO.

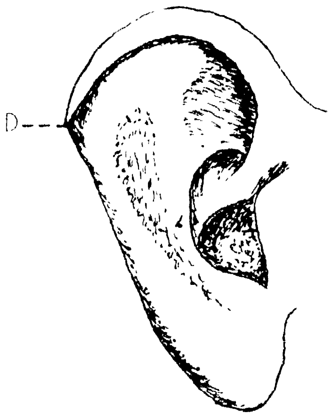

FIG. 66.—A HUMAN EAR HAVING UNMISTAKABLY LEMUROID CHARACTERS, MANIFESTING ITS DEVELOPMENT OUT OF A POINTED EAR.

D, Darwinian tubercle.

INTRINSIC MUSCLES OF THE EAR AND MUSCULATURE OF THE SKIN

intrinsic muscles of the human ear are in course of atrophy. We possess the same muscular strands in our ears as do other mammals ; we have, like them, muscles to " prick up the ear ", to turn it forward or to turn it backward, but they are extremely small, and for the most part functionless. The same is true of the intrinsic muscles of the skin. Though we hear of people's " hair standing on end ", the expression is largely metaphorical, for our hair does not " bristle " like an angry dog's, and most people go through life without the arrectores pilorum ever coming into vigorous action. (They may do so in the scalp, under the stimulus of intense fear.) The expression " obstupui, crines obsteterunt ", is not wholly metaphorical. The arrectores pilorum also react to cold in the general surface of the body by the production of " goose-flesh ". Our external ear is itself

Darwinian Ear-Tip

vestigial when compared with the large ears of many quadrupeds, which are not only mobile, but pointed—yet many human beings have, in the margin of one or both ears, the Darwinian tubercle which is a vestige of the sometime point. (See Fig. 66.) In the embryo and in the newborn baby this tubercle may be the site of a little tuft of hair.

Lanugo

A vestige of the hairy coat of our remote ancestors is found in the lanugo or down which during the last months of intra-uterine life covers the whole of the human embryo except for the palms of the hands, the soles of the feet, the lips, and certain parts of the genital organs. Usually it is shed before birth, but may persist for a few months afterwards. The insertion of the hairs on the body and limbs is remarkable. Whereas the general tendency of the hairs is to point downwards, those on our forearms point upwards —as in the anthropoid apes.

Theodor Petroff, the Dog-Man

Sometimes the embryonic hairy coat will persist into adult life, as it did in Theodor Petroff, the famous "dog-man", who when I was a lad used to be on show in Kastan's Panopticum.

Palatal Ridges

Then we have another vestigial organ in the palatal ridges, which have almost entirely disappeared in grown-ups, though they can still be felt in the front of the hard palate. In the human fœtus, however, they are plainly marked, running transversely across the whole of the palate. In lower mammals these palatal ridges are strongly developed even in adult life, and play a part in mastication.

Dental Equipment

Owing to the decreasing size of our jaws, as compared with those of our simian ancestry, our dental equipment, too, is in a somewhat atrophic condition. The set of third molars, commonly known as wisdom-teeth, are cut late or not at all, and even their rudiments may never be formed. The upper lateral incisors, too, are often very poor specimens in man. Coming, now, to the ribs, we find that man has fewer than the apes have, only 12 pairs. In the human fœtus, 13 pairs are laid down, but those which should have formed the lowest pair are subsequently suppressed.

Rudimentary Tail

A proud distinction between man and the lower animals is sometimes said to be man's lack of a tail—but he has a rudimentary one hidden away beneath his skin. The anthropoid apes share this lack and this distinction; and in the human fœtus there is at an early stage of development a protruding tail, containing, as in other mammals, from six to eight caudal vertebræ. Before birth, however, the external tail disappears, and the separate vertebræ fuse to form the coccyx. The gibbon actually has fewer caudal vertebræ than man. Now I will ask you

THIRD EYELID

to look closely at my eyes. Do you notice a small fold on the nasal side of each eye running transversely between the lids where the tiny ducts leading into the lachrymal sac open, just outside the little red eminence in the corner of the eye (the lachrymal caruncle)?

B.—Yes, I see it. Is it also a vestigial structure?

A.—It is the vestige of the third eyelid of birds, the nictitating membrane, which you can watch in the first parrot or pigeon you choose to look at, sweeping at intervals rapidly across the front of the eye and back again. The membrane is still well developed in some of the lower mammals; but in the higher mammals, as in man, it persists only as a functionless vestige. Our little toes also

LITTLE TOE

would seem to be doomed. A normal toe contains three phalanges; but in about 41% of all Europeans the little toe has only two, the ungual phalanx having fused with the middle phalanx early in intra-uterine life. The muscles supplying the little toes are likewise poorly

ATROPHY OF THE THORAX

developed. More important to our health is the atrophy that is going on in the upper part of the human thorax, which shelters the apexes of the lungs. The frequent formation of cervical ribs, rudimentary ribs articulating to the lowest cervical vertebræ, shows that the thorax once had room for larger lungs, extending farther up into the neck. Apparently this atrophy of the upper part of the thorax is still in progress, for imperfect development of the first pair of ribs is not uncommon. Such organs, regions, and parts that are

PLACES OF DIMINISHED RESISTANCE

on the down-grade are apt to be less resistant than better developed parts; they are therefore dangerous, as is shown by the frequency of inflammations and infections where they are concerned. For instance, the apex of the lung is a favourite place for the first invasion of the organism by tubercle bacilli. Again the wisdom teeth, and any other dental rudiments that fail to develop properly, are apt to be the starting-points of the growth of tumours. I have already referred to cervical fistula in the newborn, as a vestige of an embryonic gill-cleft. These considerations led Haeckel to formulate his doctrine

CAUSA FINALIS AND DYSTELEOLOGY

of purposelessness or dysteleology, as a counterblast to the assumption that there is a purposively working evolutionary force (causa finalis). The existence of these purposeless vestigial structures would, in fact, be incomprehensible, if we wanted to believe every embryological or evolutionary process to be the outcome of the workings of a supernatural power. The theory of evolution accounts for them as vestigial, as relics of our lower-animal past.

B.—Still, these are only suppositions, not directly observed facts.

EDDINGTON UPON THE VALUE OF THEORY

A.—I will answer that remark by quoting Eddington, the astronomer: "A reader who is determined to scout theory, and to regard nothing as valid but the hard facts of observation, must put all astronomical treatises on the index, for there are no unqualified facts of observation so far as the heavenly bodies are concerned. All astronomical measurements are measurements that have been made in an earthly laboratory. Nothing but theory can translate them into the knowledge of a universe that exists outside our planet." Besides, we have a touchstone by which we can ascertain the value of a theory. Theory enables us to make predictions. When subsequent observation shows the predictions to have been correct, we have convincing evidence of the soundness of the theory. Let me give you a famous instance.

BESSEL AND EINSTEIN

As far back as 1823, a German astronomer Bessel, from slight perturbations in the movements of the planet Uranus, which did not strictly follow the prescribed orbit, had deduced the existence of a yet more distant planet in our solar system. Then Adams of Cambridge in 1845 and Leverrier of Paris in 1846, from a mathematical study of the aforesaid perturbations, worked out the orbit of the unknown planet; and on September 23, 1846, Galle, another German astronomer, discovered Neptune at the appointed place in the sky. That was one of the highest triumphs of exact science to date. Let me give you another and more recent example. According to Einstein's doctrine of relativity, the principle that light moves at a uniform speed holds good when no interference by gravity is at work. Within an accelerated system and within a quiescent gravitational field, a light-ray bends, just as the trajectory of a cannon ball bends towards the centre of gravity. This distortion must result in a difference between the actual and the apparent position of the star that emits the rays. The existence of the displacement predicted on theoretical grounds by Einstein was disclosed during observations of a total eclipse of the sun on May 29, 1919. In like manner, the doctrine of evolution facilitates prediction.

THE DOCTRINE OF EVOLUTION FACILITATES PREDICTION

In the carpus (wrist-bones) of reptiles and amphibia there is a small bone, the os centrale, which is not found in the human carpus. Since, however, the human hand is supposed to have been derived from a reptilian or amphibian forbear, comparative anatomists and embryologists felt justified in assuming that an os centrale must be formed in the human fœtus, and subsequently disappear. After careful investigation, Rosenberger was actually able to discover this transient bone, so small, but so important to our biological outlook.

GOETHE

B.—You were right in warning me not to be in a hurry. I remember now that Goethe, influenced by similar reasoning, inferred the existence of a human intermaxillary bone, which in adults is fused with the upper jawbone.

Longitudinal Striation of the Caterpillar of the Privet Hawk-Moth

A.—Yes, one must always think twice before raising objections. The theory of evolution has frequently been fortified by successful predictions. Thus Weismann put forward the view that the longitudinal striation of the caterpillar of the privet hawk-moth must be of earlier date (phylogenetically) than the transverse striation or punctiform marking of most hawk-moth caterpillars, inasmuch as these likewise are longitudinally striated to begin with. He boldly asserted that the still unknown youthful form of Sphinx ligustri must be longitudinally striated. Not until ten years later did Poulton discover this marking on a sphinx larva just hatched out. But I think you have had enough evidence of this kind in support of our thesis.

B.—One thing more I should like to ask. Is it true that chemical data can furnish proof of the degree of kinship between various species of animals?

Teachings of Bio-Chemistry

Albumin of Alien Origin

Toxins and Antitoxins

Poisons Counteracted

A.—Yes, during the last few decades bio-chemistry has provided welcome confirmation of the genealogy of the animal kingdom as our conception of it finds expression in the accepted system of classification. It is a remarkable fact that, in any animal, the blood of an alien species, if injected into the circulation, has a disastrous effect, destroying the red blood-corpuscles of the recipient. This poisonous influence is more marked, the more widely divergent the two species are; when they are closely akin, and still more when we have to do with two individuals of the same species, such transfusions may have no ill-effect, or very little. Thus human blood-serum, while it disintegrates the red blood-corpuscles of a baboon, does not injure those of an anthropoid ape. Conversely, human red blood-corpuscles are destroyed by blood-serum from lower monkeys, but not by serum from anthropoid apes. We have previously discussed the valuable faculty of the living body which enables it, when a poison (toxin) is administered, or produced within it, to manufacture a counter-poison (antitoxin) which weakens or annuls the poisonous effect. Owing to this faculty, the organism can by degrees learn to tolerate very large doses of powerful poisons. Whereas the largest daily dose of morphine which can be safely administered to an unhabituated person does not exceed 1½ grains, a morphine-addict can consume as much as 60 grains a day. If the customary dose be suddenly withheld, the organism continues for a time to manufacture the counterpoison, and this, being no longer neutralised by the poison, causes very painful and even dangerous symptoms. To a lesser degree the same is true of all " habit-forming drugs ", such as are contained in tobacco, tea, coffee, etc., so that their abrupt discontinuance causes great discomfort, and the addict " craves " for his familiar poison. Experiments have shown that an animal can become accustomed to a dose of a habit-forming drug a thousand times as great as that which would kill a " raw hand ". Such immunity is acquired ; but certain animals are also naturally immune to substances which are poisonous to others. Dogs, for instance, are much less sensitive to morphine than are human beings ; and atropine, which will kill a man in a dose of 1½ grains, can be consumed with impunity by rodents in far larger quantities. Worms, pond-snails, and jelly-fish can live for weeks in a solution of strychnine, of which a teaspoonful hypodermically injected would kill a strong man. But you wanted

PRECIPITINS

to know whether and how degrees of kinship between different species can be determined by such methods. When alien albumins are injected, in the body of an animal thus treated there are formed substances known as precipitins, and when the process of injecting alien blood is systematically continued, they are formed in large quantities. These precipitins when added to the blood of the animal whose blood was used for injection, produce flocculent precipitates. If, for instance, you take a rabbit, and, at intervals of from two to six days, administer to it injections of fowl's blood in quantities of 10 c.c. at a time (when the rabbit has become habituated to the alien blood, the quantity can be increased), you will at length be able to obtain from the rabbit a blood-serum which, when added to fowl's blood, produces in this a dense precipitate. If, on the other hand, you fill your test-tube with bullock's blood instead of fowl's blood, the addition of the prepared rabbit's blood-serum will not cause precipitation. This fact would have no bearing on our discussion

ANTI-FOWL SERUM

if the effect of the prepared rabbit's blood-serum (which it will be better to call anti-fowl serum) were strictly specific.

B.—What do you mean by a strictly specific effect ?

A.—I mean that the anti-fowl serum would be strictly specific if it acted in this way only in fowls, and in no other birds. Actually, however, it produces a precipitate (though a less considerable one) when added to the blood of certain allied birds, such as the pheasant or the peacock. The amount of the precipitate is proportional to the nearness of the kinship, telling us that an animal A stands phylogenetically nearer to an animal B than to an animal C.

B.—Please give me concrete examples.

A.—An anti-sheep serum, prepared by systematically injecting sheep's blood into a rabbit, when added to sheep's blood produces a precipitate whose quantity we will call 100%. Adding the same serum to the blood of other animals, we get: in beeves, a precipitate of 80%; in the antelope, 50%; in the reindeer, 30%; in the pig, 20%; in the horse, 16%; in the cat, 12%; in the dog, 7%; and in the kangaroo, 5%. These figures indicate the degree of phylogenetic kinship. An anti-beeve serum gives results, not only in other kinds of beeves, but also, though less marked ones, in sheep, goats, antelopes, and gnus. Since these results are accordant with the notions which can be deduced from other considerations as to the kinship of various species, they can be regarded as confirming the said notions.

Bio-Chemistry and Human Racial Kinship

B.—No doubt attempts have been made to use these bio-chemical methods for the determination of man's place in the animal kingdom?

A.—Of course. The experiments led to results which are on all fours with those obtained by injection of apes' and monkeys' blood into human beings, and of human blood into apes and monkeys; and also accord with the genealogical tree which the study of comparative anatomy led Haeckel to draft for our species. The strongest reaction to an anti-human serum is naturally obtained with human blood (taken from specimens of various races); the next, somewhat weaker, with the blood of anthropoids; weaker still, with the blood of Old-World monkeys and baboons; yet weaker, in the case of New-World monkeys (platyrrhines). In the blood of lemurs (the half-apes or prosimians), a very light precipitate forms in exceptional cases only, and when a very active serum is used. These researches indicate that the bio-chemical differences between human beings, on the one hand, and chimpanzees and gorillas, on the other, are less extensive than the differences between anthropoid apes and kindred lower mammals. Fine differences are also manifest in the blood of various human races, and even as between members assigned to the same race. In the direct transfusion of blood, which has sometimes been done for severe hæmorrhage, undesirable symptoms may appear in the recipient, and are ascribed to the noxious influence of alien albumins. According to their intimate blood-reaction, human beings are divided into several "blood-groups", whose bloods are in some degree mutually incompatible. By the use of blood-reactions, it has been possible to throw light upon the phylogenetic relationships of certain animals whose place in the classificatory system had hitherto been dubious. Already in the Trias we find fossil specimens of a remarkable crustacean, the king-crab or limulus, which persists to this day. The larva of the king-crab closely resembles the long-extinct trilobites. Limulus used unquestioningly to be classed as a crustacean although in many of its characters it differs from contemporary crustaceans. Blood-reactions have shown, however, that limulus stands nearer to the scorpions and the spiders than to the

Blood-Groups in the Human Genus

Limulus (the King-Crab)

crabs, so it is now classed as an arachnid.—I will next say a few words about the practical applications of bio-chemical methods. In criminal proceedings, the life or death of an accused person may turn upon whether a blood-stain on a garment is of human or of other animal origin. To-day this can be settled beyond a doubt. Some of the clotted and dried blood is dissolved in water, and a little anti-human serum is added to the solution. If an abundant flocculent precipitate is formed, the blood-stain was human; if otherwise, not so. The reaction is so delicate that it can be depended upon even if the blood has putrefied or if the stain is many years old. A bio-chemical method

ADULTERATION OF FOOD

can also be used for the detection of many adulterations of food. We can tell with certainty when dog-flesh or horse-flesh has been used as one of the ingredients of a sausage.—Our talks to-morrow will be devoted to the forces (as far as we know them to-day) which bring about evolution from the simple to the complex, and lead to the production of countless adaptations that often border on the miraculous.

B.—I hope to hear something, too, about the general conditions of existence, and about the physical forces at work in the organism.

A.—Your wish shall be gratified.

FOURTEENTH EVENING

STRUGGLE BETWEEN THE PARTS

Conformity of Organic and Inorganic Nature

A.—As you already know, living protoplasm is built up out of the elements found in inorganic nature. Moreover, the processes of tissue-change in the cells are, from a broad outlook, subject to the general laws of chemistry. You learned, indeed, that many of these processes cannot be fully interpreted on physico-chemical (i.e. mechanical) lines, and seem to presuppose independent activity on the part of the living substance. Still, not only do the elements out of which inorganic compounds are made, combine also to form organic compounds and even living matter; but, in addition, the same physico-mechanical forces are at work in living matter as in the not-living world. Every advance in the biological sciences makes this fundamental conformity clearer. Since living protoplasm is in a fluid or semi-fluid state of aggregation, it is subject to the physical conditions valid for every fluid. Above all, it is strictly subject to the three laws of capillarity. To show you these matters in detail would take us too far afield; but I can at least give you a few examples of the way in which the origin of many seemingly purposive mechanical structures can be explained through the operation of natural (mechanical) laws without calling in "vital force" to our aid. Thus, it is easy to calculate that, in a pillar or a beam, thrusts or pulls are only exerted along particular lines or planes, the intervening portions being superfluous—mere dead weight, a hindrance rather than a help. Since engineers became fully acquainted with the laws of statics, it has become possible to build bridges, great halls, etc., containing no more than the necessary struts and ties, with an immense economy of material. Good examples of the two styles are furnished by the Dirschau railway bridges, old and new. A solid vertical steel rod 3 in. thick will support, if of a particular quality, as much as a hundredweight. Use the same amount of the same steel to make a hollow rod 4 in. in diameter, and it will bear a load of more than two hundredweight. To-day, therefore, in iron constructions, solid pillars and struts are no longer used, the material being economised by using it precisely where the stresses come.

Construction of a Support

Solid and Hollow Pillars

B.—The facts you mention were known to me, but what is their bearing on the question at issue?

THE FEMUR

A.—This. Look at a section through the head of a human thigh-bone, and you cannot fail to be struck by the way in which the fibres of the bone are arranged in accordance with the architectural or engineering principles we have just been discussing. The shaft of the bone is a tube with fairly thick walls ; but the head and neck, where in the upright posture the main pressure comes, are of a spongy structure throughout. The partitions of this " sponge ", the solid parts of the bone, run from firm wall to firm wall in straight lines and curves (planes, really, but seen as lines in cross-section) producing a pattern which cannot fail to remind you of the tracery of an iron bridge. They are struts and ties which follow the direction of the principal thrusts and pulls. Nature thus builds the bones in accordance with the rules that guide an engineer in building a bridge. The most suitable form and the greatest strength are obtained with the minimum expenditure of material. (See Fig. 67.)

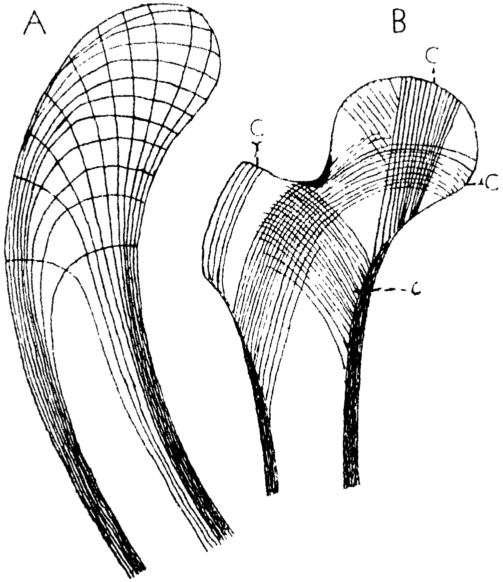

FIG. 67.—FUNCTIONAL STRUCTURES.

A, in a curved iron support ; B, in the head, neck, and upper part of the shaft of the human femur (thigh-bone) ; C, course of the struts and ties in the spongy tissue of the bone

MOST SUITABLE FORM WITH LEAST EXPENDITURE OF MATERIAL

THE BODY AS AN ENGINEER

B.—What you have just been saying, seems to me to conflict with the principle you started from, and to show that a purposeful vital force must be at work in organic processes. It is plain that the thrifty attainment of supporting strength in a bone depends upon conformity to the mechanical laws turned to account by the engineer who builds a bridge. Well, we know who built the bridge ; but in the case of the head and neck of the femur, what engineer calculated the pulls and the thrusts so that the disposition of the partitions in the spongy structure of the bone are best adapted to the needs of the case ? How could the working of blind mechanical forces result in a structure so mathematically fitted to the tasks it has to fulfil ?

Wilhelm Roux

A.—Let us see if we cannot find a natural explanation of this seeming inexplicability. The way to an understanding was pointed out by Wilhelm Roux in his theory of the struggle among the parts of an organism. You know that regular use of an organ strengthens it, whereas persistent non-use weakens it and leads to atrophy. This rule applies, not only to our muscles and other bodily organs, but also, as your personal experience must have taught you, to our mental capacities as well, and especially to memory. Roux holds that the strengthening which results from use is brought about by the specific activity of the organ concerned. In other words, a continuous or frequently repeated functional stimulus strengthens the part on which the stimulus acts. Although the increased demands made upon an organ involve intensified combustion, a greater using-up of material in the organ concerned, this enhanced consumption is more than made good by the greater capacity for assimilation which is also produced by the activity of the stimulus. As the surplus production of antitoxin to cope with a toxin shows, the organism has a tendency to react more than bare need demands in response to any stimulus. Thus stimulus encourages nutrition. If, on the other hand, the normal stimulus is lacking, assimilation flags, and the part concerned becomes weak. You can see in any boxer or wrestler how muscles that are much used increase in size and strength, whereas those that are neglected weaken and dwindle.

The Struggle among the Parts

Stimulus encourages Nutrition

Muscular Atrophy

B.—That becomes obvious to any one who has to lie up for a long time. In a motor-car accident I had several ribs broken, and one of my knees badly hurt. Although I retained an excellent appetite while I was in bed, when I got up for the first time after two months, I could hardly stand, so much wasted were the muscles of my calves, etc.

A.—Such muscular atrophy is even more marked when a joint is anchylosed. The limb thus affected is supplied with blood like the other, and there may be no reduction in the amount of food taken, but the muscles lack their functional stimulus, and they degenerate,

The Kidney

The same rule applies to all the organs. When in a human being one of the kidneys is put out of action by disease or removed by operation, while the other remains in situ and is sound, of course far more extensive demands are made upon this other kidney. The result is that it becomes greatly enlarged. But since, within certain limits, the organ has only so much and no more building material at its disposal, and since all the organs have their share of the spoil, the amount required by an organ or tissue upon which special calls are made is supplied to it at the cost of some other organ or tissue from which less is being demanded.

B.—That was clearly shown by what you told me of the stag which had broken one of its fore-legs, and in which the development of the antler on the affected side failed to occur that year because of the extra material needed to provide callus for the fracture.

A.—I am glad you remembered this appropriate instance. You can study the same sort of thing in yourself, without breaking a limb.

Bodily Work and the Capacity for Mental Achievement

When hard mental work is being done, the capacity of the body for physical exertion declines ; and, conversely, vigorous bodily labours will have an unfavourable influence on your intellectual achievements, the reason obviously being that your brain-cells are not so well nourished. According as the output of our respective organs varies, so do the characteristics of the unstable equilibrium which maintains itself among them differ. Their inter-relations thus stand in the way of any part or organ claiming and getting much more than its just share. To rephrase the matter metaphorically, there goes on within the living body a perpetual competition for the available supply of nutriment. During my researches into the origin of the gametes or reproductive cells in various species, I was able to discover a signal proof of this, for the " struggle among the parts " is especially keen in the gonads of both sexes. Here we see cells or groups of cells busied in a vigorous struggle for existence. (See Fig. 68.) If, for instance, you tear apart with dissecting-needles a fragment from the testicle of a cuttlefish, under a high power of the microscope you will discern very various cellular elements. These cells are the successive phases in the development of the spermatozoa out of the spermatogonia. The spermatogonia arise by direct transformation of the most primitive germinal cells, which protrude from the delicate cellular investment of the inner surface of the testicular vesicles. As you already know, every spermatogonium, by two successive processes of division, produces four secondary spermatocytes each of which has only half the number of chromosomes in a spermatogonium ; thereafter these secondary spermatocytes undergo a very complicated

Competition for the Sources of Nutriment

Struggle among the Parts in the Reproductive Glands

NUTRITIVE CELLS

THE CELLS VARY IN STRENGTH AS DO COMPLETE INDIVIDUALS

metamorphosis to become spermatozoa. Normally, then, each spermatogonium ultimately produces four spermatozoa. Normally, I say, and by the favour of fortune ! Many of them, however, perish by the wayside, long before this goal is reached. When I first saw this remarkable phenomenon in the male gametes of a small cuttlefish (Rossia macrosoma), I could hardly believe my eyes, and thought I must be watching a morbid process. Not until I had made careful comparisons with the origin of the reproductive cells in other animals, was I able to solve the riddle. It had long been known that in the reproductive glands of many animals, and especially in those of insects and crustaceans, numerous auxiliary cells are formed in addition to the gametes, the function of these auxiliary cells being to provide nutriment for the ova and spermatozoa in course of development. The nutritive cells fulfil their duty in various ways, and I can only tell you two of them now. In some cases, the nutritive cells extract nutritive juices from the environing body-cells, and therefore indirectly from the blood, and pass the food on to the reproductive cells. In that case they play the part of middlemen. Sometimes, however, the auxiliary cells actually serve as nutriment, being gradually devoured by the ova or the spermatozoa, as the case may be. In the little cuttlefish Rossia macrosoma, no " middlemen " cells are formed. The production of vigorous and healthy gametes is, however, of prime importance to the preservation of the species, and the before-mentioned primitive germinal cells are not equipped with a sufficiency of nutritive material for their proper subsequent development into ripe gametes or conjugative cells. Consequently there is a fierce struggle for existence among the countless reproductive cells in course of formation. They fight one with another for the food available in the testicular vesicles. Since individual cells vary in strength, etc., just as do complete individuals, the better

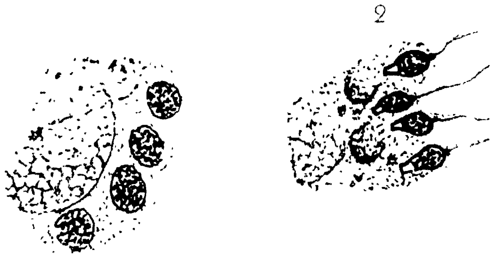

FIG. 68.—STRUGGLE AMONG THE PARTS IN THE TESTICLE OF A CUTTLEFISH, ROSSIA MACROSOMA. (After THESING.)

1, two spermatogonia in the act of dissolution, about to be attacked by four young spermatids ; 2, the spermatogonia show little trace of their original structure, and the spermatids have developed into spermatozoa at their expense equipped gametes secure more nutriment, at the expense of their weaker brethren. The upshot is that a large proportion of the would-be spermatozoa go down in the struggle, after a period of insufficient growth. Sometimes one sees cell-groups, numbering many hundreds of individuals, in a state of commencing dissolution. At first the cell-margins grow vague ; then the nuclei break up and their contents become indistinguishable from the cell-plasma, the whole cell becoming an amorphous, homogeneous mass. The more vigorous gametes are quick to take advantage of the decay of their rivals' forces. The heads of the incipient spermatozoa penetrate the masses of effete cells, and grow rapidly at the expense of these. At no stage of development are the spermatozoa immune to attack. Those that seemed to have got on nicely and to be fully matured, sometimes begin to undergo dissolution, and are then gobbled up by the survivors.

A Small-Scale Struggle for Existence

B.—In the testicles, then, though on a small scale, there is a fiercer struggle for existence than that which goes on among individual members of a species ; and in the testicles, as in nature at large, the survival of the fittest is the result ?

A.—Yes, that is so. This hidden life-or-death struggle is doubly advantageous to the species concerned. Only powerful and healthy spermatozoa can develop, and they are richly supplied with nutriment during the developmental phase. Now, powerful and healthy gametes provide the best guarantee for a strong and sound progeny. Thus a most desirable upshot is secured by a simple, crude, mechanical process of selection of the most powerful elements within the reproductive glands.—I will try to show you how the foregoing considerations can be applied to the explanation of the seemingly purposeful and certainly appropriate structure of bone. In bone, likewise, the appropriateness of its structure, the arrangement of the " struts " and " ties " to adapt the bone to the performance of its engineering function with the minimum expenditure of material, is the outcome of a struggle among the individual bone-forming cells. I have already explained to you how the increased stimulus that is the upshot of enhanced functional activity on the part of an organ or a portion thereof, leads to improved assimilative capacity, increased nutritive activity, and consequently a strengthening and a better development of the part subject to the stimulus. Now, the burden which the thigh-bone has to bear does not operate equably throughout the bone, but exerts stronger thrusts in certain directions than in others. Obviously, then, the bone-forming cells or osteoblasts that lie in the planes of greatest pressure or tension, being, as aforesaid, most vigorously stimulated to activity and growth, will most busily produce

Only Powerful Spermatozoa can Develop

Origin of Bony Structure

Osteoblasts

bony substance. On the other hand the parts lying between these planes, which receive less functional stimulation, are less well nourished, and lag behind in their development. Thus the pillar-and-arch structure is brought into being as the outcome of the working of simple mechanical forces. In one respect, moreover, this intra-organismal architectural work puts the work of any human architect in the shade. A bridge, once finished, remains as it is until it wears out, or collapses (like the Tay Bridge on December 28, 1879) because exposed to strains greater than those foreseen by the designer. But a bone is able to adapt itself to changing stresses and strains by modifying its structure.

Adaptation to Variations in Pressure

B.—Surely a bone is always exposed to the same stresses and strains ? How then can such a modification be called for ?

Fractures that have Set Awry

A.—Suppose that a fracture has set awry. Then a new adaptation will be needed, for the course of the " struts " and " ties " in the bone will no longer correspond to the new stresses and strains. Parts of the bone which previously bore the main burden, and were rendered competent to bear it by their greater strength, have been condemned to comparative inactivity ; while more extensive claims are made upon other and weaker portions. But this disharmony between function and structure does not last long. Soon the course of the fibres and plates of the bone will have been adapted to the new needs. The whole process of adaptation is physical, and there is no need to appeal to " vital force " for an explanation. The remoulding of the interior of the bone is determined by the functional claims.

B.—But the " struts " and " ties " in a bone are composed of solid substance, of calcareous deposits, outside the living cells, so I don't understand how they can be remoulded.

Formation and Absorption of Bone

A.—The osteoblasts, the cells which produce ossein (the ground-substance of bone), are capable of undoing their own work. From osteoblasts they transform themselves into osteoclasts, which soften and dissolve ossein. A study of the normal growth of bone already suffices to show that ossein-absorption and ossein-deposit go on simultaneously, or alternately, until the finished form of a bone is achieved. Whereas the customary stimuli exerted upon the cellular elements of the thigh-bone (for instance) when we walk, stand, or sit, maintain such a balance among the osteoblasts that they are quiescent—in a fractured bone that has been set awry, new stimuli come into operation and fresh cellular elements are spurred into activity. The old structure is gradually disintegrated, but in the direction of the unaccustomed stresses and strains new bony deposits are formed. These processes of absorption and deposit continue until a fresh equilibrium is established, adapted to the new needs.

Then the osteoblasts and osteoclasts lapse once more into quiescence.

B.—But the core of the problem remains for me unsolved. In virtue of what quality is living substance enabled to react purposefully to a functional stimulus? How does it come about that an awakening need brings with it the means for its own satisfaction?

Is there a Fundamental Distinction between the Organic and the Inorganic?

Crystals

Transformation of Inorganic Matter into Organic

Psychical Energy

A.—You touch upon something in which living matter really does seem to differ essentially from not-living. Still, do not the crystals of a salt always form themselves in a way characteristic of that particular salt? If a corner be broken off a crystal in a crystallising solution, is not the injury appropriately repaired? Can you explain to me why quartz always crystallises in hexagonal prisms with pyramidal ends, whereas rock-salt crystallises in cubes? (See Fig. 69.) Here, also, our knowledge is at fault, and we can only describe the facts. But it would not, therefore, occur to any one to postulate the existence of some mysterious "formative energy" lying outside the domain of the natural forces. Day by day and hour by hour we can watch plants transforming inorganic matter into organic, and can watch living matter breaking down into the inorganic constituents out of which it has been built up. Since, moreover, the history of the world forces upon us the assumption that, long, long ago, living matter must have arisen out of not-living, we have no occasion to regard this formative capacity of living matter as the expression of a fundamentally new force. It seems far more likely that we have to do with a faculty inherent in all matter, but less conspicuous in the inorganic realm. Just as the electrical energy potential in the body, only becomes kinetic, only awakens, only manifests its presence and its efficiency, when a particular combination of matter—a system—arises, so do the same considerations apply to the hypothetical energy of living substance. Experience and theory combine to make us think that inorganic matter must be primarily endowed with the prerequisites for organisation. Still, it cannot be denied that there is some justification for the widespread tendency to assume the existence of a specific psychical energy over and above chemical, mechanical, and electrical energy. To quote

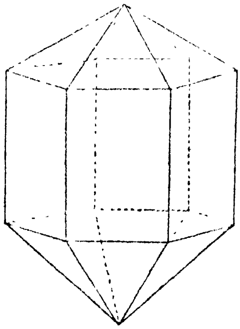

Fig. 69.—Quartz Crystal.

Wundt and the Effects of Impulse

Wundt: "Inasmuch as even a superficial study of the phenomena of evolution in the animal kingdom shows that psychical capacities increase concomitantly with the perfectionment of bodily organisation, people are generally inclined to-day to regard the latter as the cause of the former. But a more penetrating contemplation of the history of psychical evolution arouses the opposite opinion; so that we tend to believe that, through the movement it brings about, impulse reacts upon bodily organisation, leaving in this traces which facilitate the renewal of the impulsive movement, and then (since the effects of other impulsive activities are superadded) permit of the origination of more complicated impulsive manifestations." Indeed, the idea forces itself upon us that physical evolution is not the cause but the effect of psychical evolution. As Eimer insisted a good while ago, sense-organs are always found at the places where they are exposed to the strongest stimuli. Tactile organs, for instance, are on the surface of the body; eyes, where they will receive light-waves, and usually on the head; and so on. In many tubiculous annelids, on the other hand, the optical sense-organs are on the gills, which project far outside the tubes in which the creatures live. Since gravity acts equably on all parts of the body, the organs that promote the maintenance of equilibrium may be situated anywhere. As Plate insists, a specific stimulus creates an appropriate sense-organ. Unfortunately we cannot go more fully into this matter now; but the purposefulness of vital phenomena is scarcely comprehensible except on the assumption that psychical evolution determines physical organisation. We do not know whether this supposititious psychical energy will, when we acquire a fuller knowledge of vital processes, prove to be quantitatively determinable like any other form of energy, and therefore mechanically explicable. Here we reach a parting of the ways in philosophy. Certainly it is the aim of biology to refer all the processes of life to causally determined physico-chemical happenings; but this aim will not be fulfilled until an organism can be adequately represented by a mathematical formula that will enable us to predict its future vital manifestations as an astronomer can predict the movements of the heavenly bodies. We are still a long way from such an achievement—and it is even questionable whether the target may not have been wrongly chosen.

Localisation of the Sense-Organs

Philosophy and Interpretation

B.—Yet the law of cause and effect applies without restriction. Every change is evoked and determined by a previous change. An uncaused event is inconceivable.

A.—Modern physicists do not hold that view. Even in the inorganic realm they postulate limits to the dominion of causality. In our second talk, we considered the disintegration of radioactive substances into helium atoms and lead atoms. The stores of radium in our earth are being transformed at a fixed rate into helium and lead. We cannot quicken the process or slacken it. It is certain that, of 1000 radium atoms one will break up within a fixed time—but to which " the ace of spades is dealt " appears to be a matter of pure chance, and not the outcome of the working of any known law. Age seems to have no significance for the individual radium atom. " It dies ", as Jeans aptly remarks, " not because its life has been lived out, but because, for no reason in particular, fate knocks at its door." Thus you see that there are even inorganic processes which defy a causal explanation. The real chasm between the realm of the organic and the realm of the inorganic lies in this, that the former is pervaded by consciousness, whereas the latter is not. Now, whatever keys we may find to unlock the secrets of the phenomenal world, one chamber will remain to which we shall find no key—consciousness. We can acquire a most intimate knowledge of the structure of the human eye ; we can study the laws of optics in accordance with which light-rays produce on the retina a picture of an external object—but why we then " perceive ", how it is that we then become subjectively conscious of external reality, will for ever remain an enigma. A hundred times, we may trace the minute fibres of the brain ; may study the chemical transformations, the movements of the atoms and electrons, during the thought-process —still it will be inexplicable to us how a thought comes into being.

Inexplicability of Consciousness

Du Bois-Reymond

As Du Bois-Reymond once put the matter, it is utterly and permanently incomprehensible why a number of atoms of carbon, nitrogen, hydrogen, oxygen, and sulphur should not be perfectly indifferent as to the way they are arranged and to their movements towards or away from one another. Nothing can explain to us how consciousness can arise out of their interactions. The psychical processes that go on in the brain side by side with the material processes, elude, so far as we are concerned, the principle of sufficient reason. They are outside the law of causation, and are, therefore, as incomprehensible as would be perpetual motion. Only in consciousness, however, do the world and all that therein is come into being, and therefore consciousness is the primal source of all phenomena. But the recognition of this, need not and will not hinder our researches, though the goal ever eludes us. Enough of these subtleties. To-morrow we will come back to the concrete, and I will do my best to answer your question concerning the most important conditions under which this remarkable thing " life " has to exist.

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ADAPTATION TO VARIATIONS IN PRESSURE

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B.—Surely a bone is always exposed to the same stresses and strains ? How then can such a modification be called for ?

FRACTURES THAT HAVE SET AWRY

A.—Suppose that a fracture has set awry. Then a new adaptation will be needed, for the course of the " struts " and " ties " in the bone will no longer correspond to the new stresses and strains. Parts of the bone which previously bore the main burden, and were rendered competent to bear it by their greater strength, have been condemned to comparative inactivity ; while more extensive claims are made upon other and weaker portions. But this disharmony between function and structure does not last long. Soon the course of the fibres and plates of the bone will have been adapted to the new needs. The whole process of adaptation is physical, and there is no need to appeal to " vital force " for an explanation. The remoulding of the interior of the bone is determined by the functional claims.

B.—But the " struts " and " ties " in a bone are composed of solid substance, of calcareous deposits, outside the living cells, so I don't understand how they can be remoulded.

FORMATION AND ABSORPTION OF BONE

A.—The osteoblasts, the cells which produce ossein (the groundsubstance of bone), are capable of undoing their own work. From osteoblasts they transform themselves into osteoclasts, which soften and dissolve ossein. A study of the normal growth of bone already suffices to show that ossein-absorption and ossein-deposit go on simultaneously, or alternately, until the finished form of a bone is achieved. Whereas the customary stimuli exerted upon the cellular elements of the thigh-bone (for instance) when we walk, stand, or sit, maintain such a balance among the osteoblasts that they are quiescent—in a fractured bone that has been set awry, new stimuli come into operation and fresh cellular elements are spurred into activity. The old structure is gradually disintegrated, but in the direction of the unaccustomed stresses and strains new bony deposits are formed. These processes of absorption and deposit continue until a fresh equilibrium is established, adapted to the new needs.

Then the osteoblasts and osteoclasts lapse once more into quiescence.

B.—But the core of the problem remains for me unsolved. In virtue of what quality is living substance enabled to react purposefully to a functional stimulus ? How does it come about that an awakening need brings with it the means for its own satisfaction ?

Is there a Fundamental Distinction between the Organic and the Inorganic ?

A.—You touch upon something in which living matter really does seem to differ essentially from not-living. Still, do not the crystals of a salt always form themselves in a way characteristic of that particular salt ? If a corner be broken off a crystal in a crystallising solution, is not the injury appropriately repaired ? Can you explain to me why quartz always crystallises in hexagonal prisms with pyramidal ends, whereas rock-salt crystallises in cubes ? (See Fig. 69.) Here, also, our knowledge is at fault, and we can only describe the facts. But it would not, therefore, occur to any one to postulate the existence of some mysterious " formative energy " lying outside the domain of the natural forces. Day by day and hour by hour we can watch plants transforming inorganic matter into organic, and can watch living matter breaking down into the inorganic constituents out of which it has been built up. Since, moreover, the history of the world forces upon us the assumption that, long, long ago, living matter must have arisen out of not-living, we have no occasion to regard this formative capacity of living matter as the expression of a fundamentally new force. It seems far more likely that we have to do with a faculty inherent in all matter, but less conspicuous in the inorganic realm. Just as the electrical energy potential in the body, only becomes kinetic, only awakens, only manifests its presence and its efficiency, when a particular combination of matter—a system—arises, so do the same considerations apply to the hypothetical energy of living substance. Experience and theory combine to make us think that inorganic matter must be primarily endowed with the prerequisites for organisation. Still, it cannot be denied that there is some justification for the widespread tendency to assume the existence of a specific psychical energy over and above chemical, mechanical, and electrical energy. To quote

Crystals

Transformation of Inorganic Matter into Organic

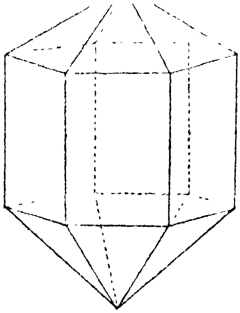

Fig. 69.—Quartz Crystal.

Psychical Energy

Wundt and the Effects of Impulse

Wundt: " Inasmuch as even a superficial study of the phenomena of evolution in the animal kingdom shows that psychical capacities increase concomitantly with the perfectionment of bodily organisation, people are generally inclined to-day to regard the latter as the cause of the former. But a more penetrating contemplation of the history of psychical evolution arouses the opposite opinion; so that we tend to believe that, through the movement it brings about, impulse reacts upon bodily organisation, leaving in this traces which facilitate the renewal of the impulsive movement, and then (since the effects of other impulsive activities are superadded) permit of the origination of more complicated impulsive manifestations." Indeed, the idea forces itself upon us that physical evolution is not the cause but the effect of psychical evolution. As Eimer insisted a good while ago, sense-organs are always found at the places where they are exposed to the strongest stimuli. Tactile organs, for instance, are on the surface of the body; eyes, where they will receive light-waves, and usually on the head; and so on. In many tubiculous annelids, on the other hand, the optical sense-organs are on the gills, which project far outside the tubes in which the creatures live. Since gravity acts equably on all parts of the body, the organs that promote the maintenance of equilibrium may be situated anywhere. As Plate insists, a specific stimulus creates an appropriate sense-organ. Unfortunately we cannot go more fully into this matter now; but the purposefulness of vital phenomena is scarcely comprehensible except on the assumption that psychical evolution determines physical organisation. We do not know whether this supposititious psychical energy will, when we acquire a fuller knowledge of vital processes, prove to be quantitatively determinable like any other form of energy, and therefore mechanically explicable. Here we reach a parting of the ways in philosophy. Certainly it is the aim of biology to refer all the processes of life to causally determined physico-chemical happenings; but this aim will not be fulfilled until an organism can be adequately represented by a mathematical formula that will enable us to predict its future vital manifestations as an astronomer can predict the movements of the heavenly bodies. We are still a long way from such an achievement—and it is even questionable whether the target may not have been wrongly chosen.

Localisation of the Sense-Organs

Philosophy and Interpretation

B.—Yet the law of cause and effect applies without restriction. Every change is evoked and determined by a previous change. An uncaused event is inconceivable.

A.—Modern physicists do not hold that view. Even in the inorganic realm they postulate limits to the dominion of causality. In our second talk, we considered the disintegration of radioactive substances into helium atoms and lead atoms. The stores of radium in our earth are being transformed at a fixed rate into helium and lead. We cannot quicken the process or slacken it. It is certain that, of 1000 radium atoms one will break up within a fixed time—but to which " the ace of spades is dealt " appears to be a matter of pure chance, and not the outcome of the working of any known law. Age seems to have no significance for the individual radium atom. " It dies ", as Jeans aptly remarks, " not because its life has been lived out, but because, for no reason in particular, fate knocks at its door." Thus you see that there are even inorganic processes which defy a causal explanation. The real chasm between the realm of the organic and the realm of the inorganic lies in this, that the former is pervaded by consciousness, whereas the latter is not.

INEXPLICABILITY OF CONSCIOUSNESS

Now, whatever keys we may find to unlock the secrets of the phenomenal world, one chamber will remain to which we shall find no key—consciousness. We can acquire a most intimate knowledge of the structure of the human eye; we can study the laws of optics in accordance with which light-rays produce on the retina a picture of an external object—but why we then " perceive ", how it is that we then become subjectively conscious of external reality, will for ever remain an enigma. A hundred times, we may trace the minute fibres of the brain; may study the chemical transformations, the movements of the atoms and electrons, during the thought-process—still it will be inexplicable to us how a thought comes into being.

DU BOIS-REYMOND

As Du Bois-Reymond once put the matter, it is utterly and permanently incomprehensible why a number of atoms of carbon, nitrogen, hydrogen, oxygen, and sulphur should not be perfectly indifferent as to the way they are arranged and to their movements towards or away from one another. Nothing can explain to us how consciousness can arise out of their interactions. The psychical processes that go on in the brain side by side with the material processes, elude, so far as we are concerned, the principle of sufficient reason. They are outside the law of causation, and are, therefore, as incomprehensible as would be perpetual motion. Only in consciousness, however, do the world and all that therein is come into being, and therefore consciousness is the primal source of all phenomena. But the recognition of this, need not and will not hinder our researches, though the goal ever eludes us. Enough of these subtleties. To-morrow we will come back to the concrete, and I will do my best to answer your question concerning the most important conditions under which this remarkable thing " life " has to exist.

FIFTEENTH EVENING

CONDITIONS OF EXISTENCE

Life and Movement

B.—We have now spent the evenings of a fortnight upon these invaluable conversations about biological problems. I have learned much, but I do not yet feel able to say what life is.

Man Friday

A.—Nor I! We are still a long way from a satisfactory definition of life. In ancient times, movement was regarded as the most important criterion of life. Everything that moves—the spring gushing forth from the rock, the flames that rise heavenward, flashes of lightning—was regarded by our ancestors of long ago, and is regarded by many primitives to-day, as spontaneously mobile because animated by a living spirit. You remember, doubtless, how Robinson Crusoe's coloured friend, Man Friday, could only explain the agitation of boiling water as due to a creature that had got into the saucepan?

B.—Very simple-minded, of course; nevertheless, movement is the most conspicuous quality of living beings. Except for fluid crystals, I cannot think of an inorganic body capable of independent movement.

Hæmokoniæ

A.—True, with certain qualifications. All the same, the concept of movement is not identical with that of life. There is no form of movement which can be regarded as specific to life. Nor is it altogether easy to distinguish spontaneous or independent movement from movement of other kinds. Just as there are inorganic bodies whose parts move vigorously, so there are living organisms (resting seeds, for instance) which show not a trace of movement. Nor does mere appearance always enable us to differentiate dead matter from a living body. If you examine a droplet of freshly-drawn human blood under the microscope, at first the only solid bodies you will see are the red blood-corpuscles and the white, but soon there show themselves exceedingly minute pear-shaped or star-shaped bodies, which move hither and thither tremulously. I will wager that your inclination would be to regard the inert red blood-corpuscles as dead, and to consider the aforesaid tiny but briskly moving bodies as instinct with life. Since no outwardly acting cause of movement is discernible, an unprejudiced observer naturally comes to the conclusion that these movements must be spontaneous.

B.—What are these bodies which seem to appear from nowhere, and to what are their movements due?

A.—They are products of the disintegration of the red blood-corpuscles, and are known as hæmokoniæ. The movements are determined by the molecular movement which goes on in every fluid. If you suspend minute particles of lamp-black in water and examine them under the microscope, you will see movements of exactly the same kind. The particles of lamp-black dance hither and thither in a way which irresistibly arouses the impression of life. Robert Brown (1773–1858), the famous Scottish botanist, was the first to describe this movement, as observed in the fluid contents of a vegetable cell, and it is therefore known as the Brownian movement. In conformity with the kinetic theory of gases, the movements of these suspended particles are believed to be due to molecular bombardment; the hypothesis being supported by the fact that the smaller the particles, the more extensive their movement. (See Fig. 70.) On the other hand, the lack of any sign of movement may make it very difficult to distinguish life from death. If you examine a little of the lees in a bottle of beer under high magnification, you will see motionless little spheres in the fluid by twos or threes, or often single. Milk presents very similar little globes, likewise motionless. But whereas the globes from the lees of beer are highly organised unicellular living creatures, namely yeast, those in milk

BROWNIAN MOVEMENT

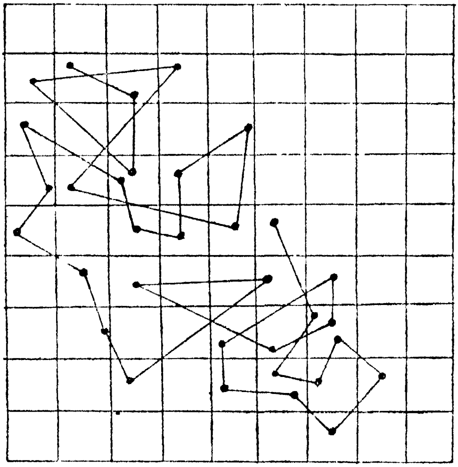

FIG. 70.—BROWNIAN MOVEMENT.

The dots and the lines show the course taken by a minute particle of lamp-black suspended in water, as seen under the microscope.

KINETIC THEORY OF GASES

YEAST CELLS AND FAT-DROPLETS

INGESTION, DIGESTION, AND EVACUATION BY AMŒBA AND CHLOROFORM DROPLET

FORCE OF MOLECULAR ATTRACTION

are only fat-droplets, and, though of organic origin, are not alive. Thus the mere presence or absence of movement is not a sufficient indication of the presence or absence of life. I told you a few evenings back how an amœba ingests its food. You can study the process remarkably well in the case of a long thread of alga, whose length exceeds many times the diameter of the amœba. Directly the alga-filament comes in contact with the surface of the amœba, the two organisms adhere, and the vegetable thread is soon surrounded by the body of the protozoon and rolled up within the body of the latter without the animal having made any conspicuously active movements. What has happened depends upon the simple physical fact that there is more adhesion between the alga and the amœba than between the alga and the water in which it is immersed. The same thing happens if you gently bring a long fibre of shellac into contact with a chloroform droplet suspended in water. The filament is sucked in by the chloroform, rolled up, and gradually dissolved. (See Fig. 71.) But the conformity is closer still. When an amœba has digested an alga-filament, it ejects the indigestible residue. Now, if you coat a fine fibril of spun-glass with shellac and bring this into contact with a chloroform droplet, it will likewise be ingested. The shellac coating will be dissolved off, and then the glass, on which the chloroform has no solvent action and to which it has no inclination to adhere, will be expelled, just as the amœba expels the indigestible parts of the alga. Were we unacquainted with the laws of molecular attraction, we should find it impossible to resist the belief that the chloroform droplet is a living organism which independently devours the shellac-coated glass filament, digests what it can make use of, and expels the residue. (See Fig. 72.)

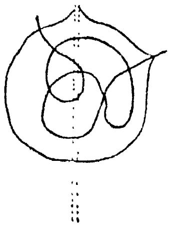

FIG. 71.—CHLOROFORM DROPLET WHICH HAS INGESTED AND ROLLED UP A SHELLAC FILAMENT. (After RHUMBLER.)

The punctiform line F shows the original position of the filament.

B.—I should never have believed there could be so much difficulty in distinguishing a vital process from one which is exclusively physico-chemical.

A.—I could give you many similar examples. Owing to these striking resemblances between the behaviour of living and not-living matter, a great deal of energy and skill has been devoted to the attempt to discover trustworthy criteria of distinction. But whereas some regard the differences as fundamental, admitting no more than that living matter and not-living matter consist of the same ultimate ingredients, the scientists of the other camp contend that no valid

Verworn

differentiæ have yet been discovered. Verworn will not even admit that metabolism is a phenomenon peculiar to living matter.

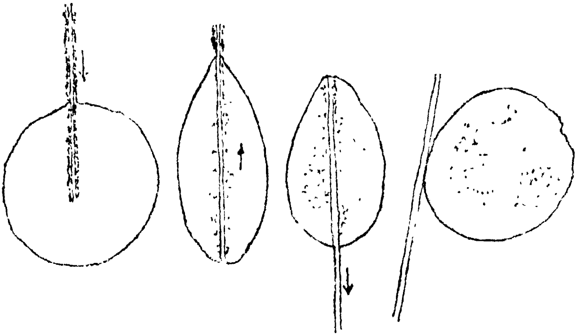

Fig. 72.—Stages by which a Chloroform Droplet ingests a Filament of Spun-glass coated with Shellac, dissolves off the Coating, and then ejects the Glass. (After Rhumbler.)

What is Metabolism ?

B.—Please tell me exactly what this term metabolism means.

A.—So long as it is alive, every organism does work, and all work implies the expenditure of energy. Just as a steam-engine cannot continue running unless it is unceasingly provided with fuel, so every living creature, unless its vital manifestations are to come to a standstill, must be continually supplied with food whose combustion furnishes it with the requisite energy. A system in perpetual motion is inconceivable whether in the organic or in the inorganic world, for it is incompatible with the principle of the conservation of energy. While nutritive material supplies the organism with the energy it needs and enables it to rebuild used and disintegrated cells and tissues, the body has to expel, not only undigested residues, but also the substances that are formed within the body when it is engaged in doing work. This never-ending (while life lasts) process of self-destruction and renewal of living substance is termed metabolism or tissue-change. All the vital processes of organisms, whether animal or vegetable, are dependent on it. In Verworn's view, however, while metabolism is a quality distinguishing a live organism from a dead one, it cannot be used as a general criterion distinguishing live organic matter from the inorganic world. Metabolic processes, he contends, are observable also in the inorganic realm. He gives

English Sulphuric Acid

as an example the behaviour of nitric acid during the manufacture of English sulphuric acid or oil of vitriol. If nitric acid is brought into contact with sulphur dioxide produced by roasting pyrites in kilns with a regulated supply of air, the sulphur dioxide deprives the nitric acid of oxygen and is transformed into sulphuric acid.

The nitric acid is reduced to nitrous oxide. If care be taken to provide for the access of a regular supply of aqueous vapour and fresh air, the nitrous oxide is reconverted into nitric acid, which continually parts with its oxygen to freshly formed quantities of sulphur dioxide. In other words, the molecule of nitric acid is continually being broken up by being deprived of its oxygen, and then reproduces itself as nitric acid once more by taking up oxygen, so that with a fixed quantity of nitric acid an unlimited amount of sulphurous acid can be converted into sulphuric. Verworn contends

METABOLISM IN THE INORGANIC WORLD

that here we have in the inorganic world, and where very simple compounds are concerned, a process strictly analogous with the metabolism of living organisms, for there is a reiteration of the decay and the reconstitution of a substance accompanied by the taking up and giving off of material.

B.—Certainly the process you describe seems to be on all fours with organic tissue-change.

INDEPENDENCE AND PURPOSIVENESS

A.—No, there is, after all, a fundamental distinction. Whereas in the living organism metabolism proceeds independently, in the manufacture of sulphuric acid there must be present as supervisor a being gifted with reasoning powers and foresight, who will see to the regular supply of air and aqueous vapour. Thus the essential characteristic of vital processes is their spontaneity, their independence. Verworn notwithstanding, we can still regard metabolism as a faculty peculiar to living organisms. Still, this does not render a sharp delimitation possible, for in many animals metabolism may be in abeyance, transiently or for long periods. A yet extremer stand-

INDEPENDENT EVOLUTION ?

point than Verworn's is that of Rinne, who will not even admit independence and purposiveness to be characteristic of organic nature at large. The best thing I can do here is to quote the relevant passage from Rinne's brilliant book *Grenzfragen des Lebens* (Borderland Questions of Life) : " If, from the outlook of a natural philosopher, we undertake a general comparison between the inorganic and the organic world, the thing that interests us most is to note the purposefulness of the evolutionary process from the simple to the complex, or (let us say) from the amœba to man. In the inorganic realm, when we study a happening, we are accustomed to look for the primary impetus. But the evolution of organised life from the Cambrian down to the present day, arouses an impression—in the independence and imperturbability of its general course—of uniqueness and autonomousness which seem to give living matter a position utterly apart from the realm of inorganic matter. Yet this impression lacks adequate justification. In the inorganic realm as well, there is a series of processes which seem to run their course no less indepen-

RADIOACTIVITY

dently, no less purposively. I refer to radioactivity. No chemical or physical force can modify radioactive phenomena, can quicken them, slow them down, or arrest them. Their development is determined exclusively by internal energies. Inevitably and unceasingly, with a stable velocity, a mass of matter containing uranium continues its transformation, giving off heat and emitting α and β and γ rays until the uranium ends up as lead. In yet another respect, these manifestations of change in the chemical elements form a striking counterpart to the evolution of organic types. As H. Driesch has pointed out, one of the puzzles of the doctrine of evolution is that amœbas (for instance) still exist; that part of their remote ancestors should have remained exempt from phylogenetic progress, and that this stock should have persisted for countless years and for millions of generations at a very low level of organic life, whereas other stocks of the same type have developed into higher forms. But if here we are faced with an enigma, we are faced with a kindred one as regards radioactivity; for although the atoms of uranium in a crystal are under identical conditions, still a choice is made as to which from among them shall continue their march to become atoms of lead. We cannot say what decides why one uranium atom shall remain for ages a uranium atom, and another shall here and now disintegrate. The same mystery faces us in both fields, the organic and the inorganic."

B.—Rinne's parallel seems to me very striking, and one to which few objections can be raised.

THE AMŒBA, TOO, HAS A HISTORY

A.—I have a good many criticisms. No doubt it is true that down to the present time the amœba has remained at the organisational level of a unicellular animal, but it does not follow therefrom that the creature has persisted as unchanged in type as the uranium atom in a crystal. Among the protozoa there can be, and there certainly has been, advance in organisation. It is an unwarranted assumption that the unicellular animals of earlier geological ages stood at the same level of organisation as our contemporary protozoa. Besides, the fact that many classes of animals have persisted almost without change of type for vast periods of time, is not a formidable argument (though often regarded as such) against the general validity of the theory of evolution. The error arises from our homocentric way

LOWER AND HIGHER ORGANISMS

of speaking of "lower" and "higher" organisms. An amœba or a worm may be quite as well adapted to its environment as a human being. If the conditions of existence for a being well adapted to them have remained unchanged through long geological periods, there will have been no stimulus to change. The persistence of appropriate forms without modification, at the same organisational level, when there has been no change in environing conditions, although, during the same epoch, kindred forms whose environing conditions were changing have undergone extensive transformations, is one of the arguments for, and not an argument against, the doctrine of evolution. Here is another point against Rinne. The uranium atom moves on towards its goal of transformation into lead. Then its evolution ceases. Of a living type we can never say that it has reached its definitive form. Rinne's parallel deals only with externals, not with inward essentials.

METABOLISM AND PURPOSIVENESS PECULIAR TO THE ORGANIC WORLD

B.—You hold, then, that metabolism and purposiveness are the distinctive characteristics of the organic world, those which set it apart from the inorganic?

A.—Yes.

B.—Are there any other general differentiæ?

CHOICE OF NUTRIMENT CHARACTERISTIC ALSO OF CRYSTALS

A.—Can you yourself think of any features that are present in living creatures, but never found in not-living bodies?

B.—Two that occur to me are nutrition and growth.

A.—Develop your points a little.

B.—Well, a living organism chooses out of its environment certain substances as nutritive, those substances that are fitted to be transformed into the material of its own body, and it grows through having ingested them; whereas crystals, which also grow, do not appear to be capable of such a choice, and grow only by the accretion of material on the surface, not by imbibition or ingestion.

A.—You are lumping good arguments and bad. It is true that organisms exercise a careful choice among possible nutritive materials, and that when they grow it is through having ingested what they have chosen. It is also true that the growth of a crystal is mainly due to surface deposit. But a crystal must be no less fastidious in its choice of materials than a living organism. Foraminifers, for instance, make their shells exclusively out of the carbonate of lime they extract from sea-water; certain radiolarians employ nothing but silica, rejecting carbonate of lime; and other radiolarians specialise in the use of strontium sulphate. But crystals are just as fastidious. Quartz will build its body only of silica; whilst rock-salt crystals grow exclusively by the deposit of sodium chloride. As regards granite, which has crystallised out of the magma (the molten interior of the earth), Rinne gives an interesting diagram showing which substances are accepted and which are rejected by these crystalline rocks. Among the rocks, there are omnivores, like biotite, and others, like quartz, to which only one salt is acceptable. Here, then, the harmony between the organic and the inorganic world goes beyond mere analogy. Nor can the tendency of living organisms to gain

FORAMINIFERS AND RADIOLARIANS

OMNIVOROUS CREATURES AND FASTIDIOUS ONES

Intussusception and Apposition

their food-supply by ingestion or intussusception, as contrasted with surface deposit (apposition), be regarded as a fundamental distinction. Certain crystals, too, take substances into their interior. Lehmann has proved that this is done by many fluid crystals, which in other respects, too, remind us so much of the simplest living organisms by their spontaneous movements and by their undergoing fission. On the other hand, the formation of the cellulose wall of a vegetable cell and that of the calcareous otoliths found in the auditory organs of fishes, etc., takes place by apposition. These considerations will suffice to show you how difficult it is to draw a sharp distinction between the living and the not-living.—You also wanted to know what are the indispensable prerequisites to the normal course of life. One essential condition, nutriment, has already been discussed. Unquestionably the substances out of which the various living organisms derive energy, heat, and the materials needed for building up their living substance, are extremely diversified. Whereas animals can only make protoplasm out of organic compounds, prepared for them by plants or other animals, the sources of vegetable nutriment are in the atmosphere, in water, and in the mineral contents of the soil. Plants, however, can only utilise these sources with the aid of another indispensable condition—light. Not until stimulated to chemical activity by sunlight can leaf-green, or chlorophyll, split up

The Sun as the Primary Source of Life

the absorbed carbonic acid into carbon and oxygen. Since, in the last analysis, animal nutrition is only rendered possible by this activity of plants, the sun is the primary source of all life.

B.—Now that you have given me an account of animal metabolism, I wish you would go on to a fuller description of metabolism in plants. How has it been ascertained whence plants obtain the substances necessary to their growth ?

Metabolism in Plants

A.—The investigations are so simple that you can carry them on for yourself at home. The body of a living plant, like that of a living animal, consists predominantly of water ; and, next to this, carbon plays a very important role. Since you feed your stove with wood, you know that the dried parts of plants burn, and that they burn because they contain large quantities of carbon. This substance is absolutely essential to the growth of plants, for it is an ingredient of almost every compound found in the vegetable organism. Carbon can enter into the most diversified combinations with other elements, and it is upon this faculty that the formation of most vegetable substances depends. Culture experiments show, however, that, in addition to carbon, a plant needs potassium, calcium (lime), magnesium, sulphur, phosphorus, and iron. You would like to know,

What does a Plant Eat ?

of course, whence a plant obtains the various elements requisite to

Culture of Plant on Nutritive Solution

Transformation of Carbonic Acid into Carbon

its growth. To study this, take a glass beaker containing a litre of *distilled* water, in which you will dissolve a gramme of calcium nitrate, a quarter of a gramme of nitre (potassium nitrate), with the same amount of magnesium sulphate and calcium phosphate. Add also a few drops of a solution of ferric chloride. Close the mouth of the beaker with a bored cork, inserting into the aperture of the cork a grain of maize, so that when the maize germinates, the rootlets can grow down into the nutritive solution. Place your beaker thus prepared in a window on which the sun shines ; and be careful, if the level of the water lowers because of evaporation in spite of the cork, to fill up from time to time with distilled water. Although there is no earth, the grain of maize will soon grow into a fine plant. Growth primarily takes place at the cost of the nutritive substances stored in the seed, but these stores are soon exhausted, so the materials needed for further growth must derive from other sources. Where can the grain of maize get them ? Only from the nutritive solution and from the air. Consequently our maize plant must build up its bodily substance out of inorganic materials. Now there are no organic carbon compounds in the nutritive solution, which consists of nothing but water and inorganic salts. Nor does the atmosphere contain free carbon. The fact that the maize plant thrives just as well when its roots dip into the nutritive solution as if it were planted in the earth, shows that the carbon compounds in the humus are not indispensable, and, indeed, they cannot be utilised by the plant as sources of carbon. The only remaining possibility is the carbonic acid which is present in the air, though in a very small proportion (i.e. four volumes in ten thousand). True, the water of our ponds and streams contains carbonic acid in solution, but we are using distilled water, which has been freed of carbonic acid by the process of distillation.

B.—Still, I am puzzled how the plant can get carbon out of the carbonic acid in the atmosphere.

Chlorophyll Granules

A.—The formula of carbonic acid is CO_2, this meaning that a molecule of carbonic acid consists of one atom of carbon combined with two atoms of oxygen. When decomposed, carbonic acid splits up into carbon and oxygen. In plant-cells, such a splitting-up is effected by the chlorophyll granules with which all the green parts of plants are abundantly supplied. But chlorophyll can only do its work when the sun shines on it. The oxygen thus set free is exhaled by the plant, whereas the carbon is used to build up carbohydrates with the aid of water absorbed by the roots.

B.—I take your word for it. But the experiment has not so far made plain that carbonic acid is split up by the chlorophyll granules, that the oxygen is exhaled, and that the carbon is built up into the structure of the plant.

Oxygen

A.—Yes, you are right. All that we have proved so far is that the carbonic acid in the air is the only possible source of the carbon in the plant—for there are no carbonates in the nutritive solution. The liberation of oxygen by the plant, however, shows that somewhere and somehow it must dissociate carbonic acid into carbon and oxygen. If you cut off a twig of the common water-weed (Elodea canadensis), fasten it in water charged with carbonic acid, and put the glass container in the sunshine, bubbles of gas will exude from the cut surface. They continue to do so as long as the sunshine lasts, but speedily cease to appear when the vessel is put in the dark. They also cease to appear if pond-water is replaced by distilled water (which contains no carbonic acid). Thus the discharge of oxygen only takes place when the green parts of the water-weed are exposed to sunlight, and when the water contains carbonic acid.

B.—How is it known that the bubbles of gas are oxygen ?

A.—You must have learned in your chemistry class that when a still glowing match is thrust into oxygen, it bursts into flame. If you collect the gas-bubbles issuing from the cut surface by making a miniature pneumatic trough out of an inverted test-tube filled with water, you can test the gas in the way just mentioned, and thus satisfy yourself that it consists mainly, if not exclusively, of oxygen. I think what I have told you must have convinced you (though it is still more convincing to do the experiment oneself) that in the green parts of plants exposed to sunlight a decomposition of carbonic acid or carbon dioxide into carbon and oxygen actually occurs. The green parts of all plants act in the same way as the water-weed, but only the green parts. If you try the same experiment with a slice of raw potato (the tuber), or with a colourless potato-shoot which has grown in the dark, or with any fungus, no gas-bubbles will be emitted in the sunlight. Additional proof that the chlorophyll granules are indeed the effective agents in this matter is furnished by the fact that in these granules are formed starch-grains, composed of carbon, oxygen, and hydrogen, as the first products of the assimilation of carbon from the atmosphere and its combination with water to produce a carbohydrate. With this starch to begin with, the plant is then able, by combining it in various ways with other elements derived from the soil or the nutritive solution, to build up all the organic compounds it needs, albumin not excepted. For vigorous and healthy growth there must, above all, be an adequate supply of nitrogen. Although the atmosphere contains 79% of nitrogen, plants (except for certain nitrifying bacteria found in the tiny tubercles on the rootlets of leguminosæ) cannot turn this nitrogen to account. They obtain the nitrates they need ready-made from the soil, and after a time " exhaust " the latter, so that the supply of combined

The First Product of Assimilation

Demand for Nitrogen

its growth. To study this, take a glass beaker containing a litre of distilled water, in which you will dissolve a gramme of calcium nitrate, a quarter of a gramme of nitre (potassium nitrate), with the same amount of magnesium sulphate and calcium phosphate. Add also a few drops of a solution of ferric chloride. Close the mouth of the beaker with a bored cork, inserting into the aperture of the cork a grain of maize, so that when the maize germinates, the rootlets can grow down into the nutritive solution. Place your beaker thus prepared in a window on which the sun shines ; and be careful, if the level of the water lowers because of evaporation in spite of the cork, to fill up from time to time with distilled water. Although there is no earth, the grain of maize will soon grow into a fine plant. Growth primarily takes place at the cost of the nutritive substances stored in the seed, but these stores are soon exhausted, so the materials needed for further growth must derive from other sources. Where can the grain of maize get them ? Only from the nutritive solution and from the air. Consequently our maize plant must build up its bodily substance out of inorganic materials. Now there are no organic carbon compounds in the nutritive solution, which consists of nothing but water and inorganic salts. Nor does the atmosphere contain free carbon. The fact that the maize plant thrives just as well when its roots dip into the nutritive solution as if it were planted in the earth, shows that the carbon compounds in the humus are not indispensable, and, indeed, they cannot be utilised by the plant as sources of carbon. The only remaining possibility is the carbonic acid which is present in the air, though in a very small proportion (i.e. four volumes in ten thousand). True, the water of our ponds and streams contains carbonic acid in solution, but we are using distilled water, which has been freed of carbonic acid by the process of distillation.

CULTURE OF PLANT ON NUTRITIVE SOLUTION

TRANSFORMATION OF CARBONIC ACID INTO CARBON

B.—Still, I am puzzled how the plant can get carbon out of the carbonic acid in the atmosphere.

A.—The formula of carbonic acid is CO_2, this meaning that a molecule of carbonic acid consists of one atom of carbon combined with two atoms of oxygen. When decomposed, carbonic acid splits up into carbon and oxygen. In plant-cells, such a splitting-up is effected by the chlorophyll granules with which all the green parts of plants are abundantly supplied. But chlorophyll can only do its work when the sun shines on it. The oxygen thus set free is exhaled by the plant, whereas the carbon is used to build up carbohydrates with the aid of water absorbed by the roots.

CHLOROPHYLL GRANULES

B.—I take your word for it. But the experiment has not so far made plain that carbonic acid is split up by the chlorophyll granules, that the oxygen is exhaled, and that the carbon is built up into the structure of the plant.

OXYGEN

A.—Yes, you are right. All that we have proved so far is that the carbonic acid in the air is the only possible source of the carbon in the plant—for there are no carbonates in the nutritive solution. The liberation of oxygen by the plant, however, shows that somewhere and somehow it must dissociate carbonic acid into carbon and oxygen. If you cut off a twig of the common water-weed (Elodea canadensis), fasten it in water charged with carbonic acid, and put the glass container in the sunshine, bubbles of gas will exude from the cut surface. They continue to do so as long as the sunshine lasts, but speedily cease to appear when the vessel is put in the dark. They also cease to appear if pond-water is replaced by distilled water (which contains no carbonic acid). Thus the discharge of oxygen only takes place when the green parts of the water-weed are exposed to sunlight, and when the water contains carbonic acid.

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THE FIRST PRODUCT OF ASSIMILATION

DEMAND FOR NITROGEN

Leaving the other ingredients out of consideration, our atmosphere contains (by volume) 21% of oxygen and 78·06% of nitrogen. The pressure exerted by the atmosphere on the surface of our bodies at sea-level averages 14·7 lbs. per square inch, and this pressure is known as " one atmosphere ". It is that under which animals and plants for the most part live on dry land. It can, however, be considerably varied without the change causing any serious disturbance, and the same remark applies to the oxygen-content of the atmosphere.

Pressure and Oxygen-Content

Animals and plants can live permanently in air whose oxygen-content has been reduced to 16%. The body adapts itself to the reduction of oxygen, and the consequent interference with the normal respiratory exchange of gases, by a notable increase in the number of red blood-corpuscles. But when the oxygen-content of the air is yet further reduced, to about 11%, this method of compensation does not suffice ; cardiac and respiratory distress manifests itself, and reduction beyond this point leads to death from oxygen-starvation. Although the proportional composition of the atmosphere is the same at high altitudes as at sea-level, the lowered pressure at the former imposes difficulties in the way of the respiratory exchange of gases, and symptoms of oxygen-starvation likewise ensue. For that reason, balloonists who are going to very high altitudes, and mountaineers who are trying to scale the loftiest mountains such as Mt. Everest (over 29,000 feet), take cylinders of condensed oxygen and an inhaling apparatus with them. Cold-blooded animals, having much more sluggish combustive processes than warm-blooded, are naturally less sensitive to scarcity of oxygen. Whereas a rabbit is seized by convulsions and dies within a few minutes when the oxygen-content of the air is very low, a frog can survive several hours in air from which all the oxygen has been removed.

Need for Oxygen

B.—Is there, then, so marked a difference between the need for oxygen in different kinds of animals ?

A.—Let me give you a few examples. Per kilogramme of body-weight, a robin consumes in an hour nearly 12 grammes of oxygen ; a rabbit, only about 1 gramme. The oxygen-consumption of a human being (reckoned on the same scale) is about 0·5 gramme, and that of a frog about 0·07 gramme. An increase in the oxygen of the inspired air is, within limits, harmless. At ordinary atmospheric pressure, mammals can live a long time in pure oxygen ; but an increase of the pressure to 3 atmospheres is quickly fatal, and (strangely enough) with symptoms resembling those of suffocation. On the other hand, if the composition of the air be normal, animals can bear an increase of pressure up to 15 atmospheres ; provided the increase, and still more the decrease, be not too rapidly effected. Within certain limits, the dangers of too low an oxygen-content can be compensated by an increase of pressure ; and the dangers of too high a pressure, by a reduction in the oxygen-content.

Water-Pressure

B.—In deep waters, animals are exposed to very high pressure. I suppose they can endure it because the oxygen-content is low?

A.—Perhaps that is true to some extent, but the decisive part has certainly been played by a process of gradual adaptation. Thus

Life in the Depths of the Sea

there is abundant life in the ocean depths at a pressure of several hundred atmospheres, the fauna including higher animals, such as cuttlefish and strangely-formed crustaceans and fishes. Even whales, as we learn from the contents of their stomachs, can dive or " sound " to a depth of 500 metres. Plant-life is, of course, impossible at such depths, for the transparency of sea-water is restricted, and no light penetrates beyond 400 metres. Fish brought swiftly to the surface from great depths by an exploring net perish immediately, burst by the expansion of the swimming-bladder, or are at any rate terribly distended by the expansion of the pharynx and gut. As

Excess of Pressure is Fatal

Regnard showed, at a pressure of 700 atmospheres the activity of the organisms of putrefaction ceases, so that meat and blood stored at such a pressure remain fresh indefinitely. Infusoria, worms, crustaceans, and molluscs exposed to so high a pressure manifest a slackening of the vital activities within a few minutes, and soon these activities are completely arrested. If, however, the animals are gradually and soon enough restored to normal conditions of pressure, they awaken to new life. A long continuance of the pressure

Desiccation-Rigor

kills them. Desiccation (withdrawal of water) makes protoplasm hard and stiff, this being technically known as desiccation-rigor. The example of Triops cancriformis has, however, shown you that the condition is not necessarily fatal, for organisms can recover from it after having been thus " leathery " for several years. The spores

Resting-Stage in Seeds

of many bacteria remain alive for as long as ten years, and there can be no doubt that seeds can germinate after twenty years. For many seeds, indeed, a prolonged " resting-stage " is advantageous. Cucumbers raised from seed two or three years old are hardier and grow more quickly than those raised from fresh seeds. But there is a limit, and the stories of grain grown from " mummy wheat " dating from the days of the ancient Egyptians are apocryphal.

Is there such a Thing as Suspended Animation?

B.—In these resting seeds is vital activity completely suspended, or only so far reduced that we cannot perceive it?

A.—If any active vital process were going on in a seed, there would be metabolism and respiration. Careful researches seem to show that there is nothing of the kind. Koch stored considerable quantities of seeds in sealed glass tubes out of which all the air had been pumped. When these tubes were opened after many months, no trace of carbonic acid could be detected in the interior, as would surely have been the case had any vital processes been going on.

B.—That is tantamount to saying that in these seeds life was arrested. If so, they were dead. How, then, could they subsequently germinate ?

A.—Suppose the falling of a stone to be arrested by an obstacle. You would not say that, though manifestly at rest, it must be imperceptibly moving. No, it is really resting. Yet as soon as the hindrance is removed, it continues to fall. Why can there not be, in like manner, a temporary arrest of the vital functions ? It is a question of terms. Can we say that an organism in such a condition is truly living ? Surely vital functions must be going on if there is life ? Yet you cannot say that a seed in the resting-stage is dead, for it bears within it the potentiality of life. You may say that it is seemingly dead ; or, perhaps better still, to use an old phrase, that it is in a condition of " suspended animation ". Such an organism resembles a watch which has been wound up, but has not been given the little shake requisite to set the balance-wheel in motion ; whereas a dead animal or plant resembles a watch with a broken mainspring.

Fauna of Roof-Gutters

In old moss or the dirt that lodges in roof-gutters there live many lower organisms known collectively as the roof-gutter fauna. If you take a pinch of dust from a pad of moss and put it on a glass slide, then add a little water, cover with a cover-slip, and examine your treasure-trove under the microscope, you will soon see some of the ostensible grains of dust swell up and begin to move ; among them will be vigorous animalculæ, graceful radiolarians, and lively amœbas. As the water dries up, the movements become sluggish, and then cease ; the living bodies shrink ; until once more you see nothing but particles of dust and grains of sand.

B.—How long can such creatures retain the potentiality of revival in a condition of suspended animation ?

A.—Radiolarians, infusoria, and tiny crustaceans can be recalled to life by moistening them after several years' desiccation. The roof-gutter fauna is also remarkably insensitive to heat and cold. The example of the Australian mudfish (Neoceratodus forsteri) has shown that even higher animals can spend months in a resting-stage of partial desiccation.

B.—The same is true of higher plants. I ordered a rose of Jericho from a nursery garden in Erfurt and received a shrunken, dry, brownish structure. When I moistened it, however, the branches and twigs quickly swelled up.

Resurrection of Plants

A.—An unfortunate example. The rose of Jericho is actually dead. Its alleged blooming, the swelling-up of the dried twigs, is a purely mechanical, hygroscopic phenomenon, and not a restoration from suspended animation. It is different, however, with the Californian Selaginella rediviva, which you could also have got from Erfurt. This plant is really capable of an apparent death which can be followed by resurrection. For years you can put away a dried selaginella in a drawer, but as soon as you wet it, or plant it in a flower-pot and water it, it opens out, turns green, and puts forth new shoots. The sudden appearance of fresh vegetation amid the arid rocks of the Cordilleras after a shower of rain is mainly due to the resurrection of selaginella. The great resistance of certain organisms to high temperatures is shown by the presence of living algæ and bacteria in the hot springs of Yellowstone Park. Even more insensitive (owing to the small amount of water they contain) are certain protoplasts in the resting-stage. The spores of many bacteria will survive boiling for an hour. Dried anthrax spores do not succumb at a temperature of 140° C. until they have been exposed to it for three hours. Seeds of grass and other grains, artificially dried, will withstand dry heat of over 100° C. for more than three hours without losing the power of germination. Many unicellular organisms are also markedly resistant to extreme cold. A number of different kinds of bacteria survived a week's exposure to a temperature of – 225° C. This provides theoretical possibility for the soundness of the cosmozoic theory, according to which the germs of life reached the earth across the vast and intensely cold regions of outer space.

Resistance to Heat and Cold

B.—I suppose, however, such resistance is only possible in the case of lowly organisms?

A.—Indubitably the sensitiveness to external influences increases with advancing differentiation, with increasing complexity of structure. A townsman who has led a sheltered life succumbs to hardships and is worn out by violent exertions sooner than a peasant who is inured to them. Almost invariably a gain in one direction has to be paid for by a loss in another. From the biological standpoint, therefore, we should not speak of lower and higher, but only of simpler and more complex organisms, for if we take tenacity of life and degree of adaptation to the conditions of existence as our standard of what is higher, then we must class many bacteria and protozoa as higher organisms, perhaps as the highest. Still, there are certain vertebrates endowed with an amazing tenacity of life. In a small aquarium I kept some loach. Entering the unheated room one very cold day, I found the container burst, and the fish enveloped in a block of ice. I thawed them out slowly and carefully. Soon they were swimming hither and thither as cheerfully as ever. I have seen the like recovery, after freezing, in frogs and snakes. It used to be believed that when such "frozen" animals could be resuscitated, they had not really been frozen through and through, and that death would certainly take place if all the bodily fluids were frozen, but

Cold may suspend Animation

numerous experiments made on various kinds of animals by Power, Preyer, Pictet, and myself have shown that this is not so. Preyer slowly froze two frogs, gradually lowering the temperature to – 2·5° C. Opening one of the frogs, he found that the blood was frozen hard. The control specimen was then carefully thawed, and soon its heart began to beat once more. After a while, it resumed its ordinary avocations and seemed to have suffered no harm. With equal success, Pictet cooled frogs and snakes to – 28° C., and snails even to – 120° C. Since at such very low temperatures all chemical processes cease, these experiments give additional proof of the possibility of what I described above as suspended animation.

Hibernation

B.—Many of the higher mammals, such as bats, hedgehogs, badgers, hamsters, brown bears, etc., pass into a rigid and motionless state during the winter months. Are they in a condition of suspended animation ?

A.—No, their vitality is merely lowered. The depth and the length of the winter-sleep varies from one species to another, but this hibernation, as it is called, is always associated with a marked slackening of metabolism. Breathing almost ceases, the activity of the heart is barely perceptible, and the body-temperature, which in the waking and active state is the same as that of other warm-blooded creatures, sinks to near freezing-point. Strangely enough, in mammals that do not hibernate the newborn are more resistant to low temperatures than their parents. This is additional confirmation of the doctrine of descent. According to the theory of evolution, warm-blooded mammals, whose temperature ranges from 35° C. to 40° C. whatever the temperature of the environment may be, have developed

Cold-Blooded Animals

from ancestors whose temperature varies with that of their surroundings (" cold-blooded animals "). A transition between the " warm-blooded animals " with a fixed temperature independent of environment, and the animals with a variable temperature (our presumably reptilian ancestors), is presented by the ant-eater, which is subject to variations of temperature, corresponding to those of the environment, of as much as 10° C. Birds, the higher mammals, and man,

Regulation of Body-Temperature

on the other hand, keep the blood and the body at a fixed temperature, no matter whether the environment be much hotter or much colder. They have special physiological arrangements for maintaining this constant temperature. In a healthy human being the temperature seldom varies by as much as a degree from the " normal " of 37° C., whether in the greatest heat of summer or in the severest cold of winter. This is a matter of great importance to us, for the fixed temperature (which except in tropical heat is considerably above that of the environment) is not merely the effect of the combustive process we call metabolism or tissue-change, but is indispensable to healthy metabolism.

B.—How is the body-temperature of warm-blooded animals maintained at a fixed level?

A.—One important means of checking a rise of temperature from exertion or from an unusual increase in the temperature of the environment is the activity of the sweat-glands. The evaporation of sweat from the surface of the body has a powerful cooling effect. Heat also increases the frequency of the breathing, so that more aqueous vapour is exhaled from the lungs. Also, when we grow hot, the capillaries of the skin expand, so that more heat is directly discharged from the surface of the body. The inverse processes, when desirable, automatically check an undue loss of heat. Dogs, which have no sweat-glands in their skin, hang out their tongues and pant when they grow hot, secreting at the same time very large quantities of saliva.

B.—Why do some animals hibernate, others not?

A.—The question is not easy to answer. For many animals which are nourished upon insects or plants, but which cannot, like birds, easily seek warmer climes at the approach of winter, hibernation is essential to life. They would starve unless, by hibernation, they could reduce tissue-change to a minimum. Even during the winter-sleep, a certain amount of loss of substance continues. They make this good by calling upon their own stores of fat, accumulated during the warm and prosperous season. When hibernation begins, they are exceedingly plump, all their organs being thickly invested with fat. On awaking in the spring, they look lean and wasted, for many hibernators lose as much as one-fourth of their weight during the winter-sleep. Other hibernators, those whose sleep is less profound and long-lasting, provide a store of food in autumn, and eat whenever a warm spell awakens them.

Duration of Winter-Sleep

B.—How long may such a winter-sleep last?

A.—In the hamster and the squirrel only from two to three months, as a rule. Bats, on the other hand, spend as long as six months in winter-quarters. Many animals, too, will fall asleep even in warm weather, to tide them over a period of scarcity. The dormouse, for instance, falls asleep for several weeks in May or June. In certain tropical mammals, such as the centetid (Centetes ecandatus), an insectivore of Madagascar, the winter-sleep is replaced in the hottest season by a summer-sleep, which reminds us of desiccation-rigor. Many snails, too, are subject to long periods of rest. Our garden snails, for instance, close their houses with a calcareous obturator when winter approaches, and do not open again until late in the spring. Luther and Westerlunds have kept snails fifteen years in a state of desiccation-rigor, and have awakened them to renewed life by sprinkling them with water. In regions where prolonged drought is common, this capacity for remaining alive for lengthy periods in a dry resting-stage is of primary importance to the preservation of the species.

FAKIRS

B.—In stories of travel in the East Indies, we often read that fakirs can voluntarily pass into a rigid state of suspended animation, during which they can even be buried, to be exhumed and revived after several weeks.

A.—These "travellers' tales" are almost certainly apocryphal. The travellers may have reported in good faith, but had been humbugged. Still, there is good scientific evidence for occasional cases of simulated death, so there may be a kernel of truth even in the stories you mention. It would certainly be wonderful if the aforesaid fakirs could remain in a state of suspended animation for weeks. Nevertheless, there are more things in heaven and earth than the wisdom of the schools accepts or science can account for. Among these are the phenomena of hypnotism, which may culminate in complete rigidity (catalepsy), with a marked depression of the chief vital functions. Lower animals can be hypnotised as well as man. If you seize a fowl firmly but gently and lay it on its back, it will, after a few defensive movements, lie still as if under a spell; or (as Pater Athanasius Kircher described in his *Ars magna lucis et umbrae*, 1646), if you hold it with its beak to the floor and draw a chalk line forward away from the beak, it will likewise remain rigidly fixed to the spot.

B.—Is there any explanation of this remarkable behaviour?

CATAPLEXY

A.—There is a name for it, and you can call it an explanation if you like. The hen is said to be in a condition of cataplexy, or fear-rigor; or, to talk in the vernacular, the creature is dazed. It has been known for thousands of years that a cobra (Naia tripudians), if pressed firmly by the neck for a short time, becomes motionless, so that it will stay in any position you choose to impose on it. Perhaps that accounted for Moses' miraculous transformation of a staff into a serpent! Nor are the phenomena of "fascination" fabulous. It is true that many animals pass into a condition of fear-rigor at sight of a snake. I have myself seen a mouse which I dropped into an adder's cage make no attempt to run away, but quietly allow the snake to swallow it. Human beings, likewise, are sometimes "paralysed by terror". There are two contradictory reactions to extreme peril, the instinct to run away, and the instinct to cower motionless. Either may, as circumstances vary, promote escape from the threatening danger.

B.—I suppose that is why many beetles, when seized, draw legs and antennæ close to the body and "sham dead"?

A.—Yes. This fear-rigor is an advantageous adaptation, for many predatory animals will only attack their prey when it is moving. Here "shot while trying to escape" is not a fable but a fact. Belt saw a number of walking-leaf insects in the way of a train of driver ants. Some of them were paralysed by fear, and were ignored by the ants; others tried to escape, and suffered for it. A sturgeon that has been netted will sham dead and turn on its back. Many higher animals seek safety in the same expedient. The opossum, when in danger, shams death, continuing to do so even when struck. (Hence the phrase "playing possum".) Now I should like to say

Immunity to Poison

a few words about the reaction of many organisms to chemical noxious influences. Elsewhere we have discussed immunity to poison. In zoological study, absolute alcohol and osmic acid are two of the strongest preservatives we have. These fluids will in a few seconds kill most small creatures and harden their tissues. In the course of an investigation of the water-dwelling larvæ of a fly known as Corethra plumicornis, I dropped some of them into a glass containing very strong alcohol. They were still swimming vigorously after several hours' immersion, and they did not succumb to the poison until a number of days had elapsed. They were equally resistant to osmic acid.

Eels in Vinegar

B.—There are tiny eel-shaped creatures about $\frac{1}{12}$th of an inch long which thrive in vinegar, so destructive to animal life in general.

A.—Yes, nature's capacity for enabling animals to find a habitat in the most unlikely places seems inexhaustible. No less strange than the life of "eels" (Anguillula aceti) in vinegar, is that of protozoa, bacteria, and worms in our intestine, and their power to resist the digestive juices. In truth, this is no more remarkable than that the stomach and intestine do not digest themselves. As you already know, they are saved by forming an antitoxin. Under morbid conditions, when the formation of the necessary antitoxin fails to occur, self-digestion of the stomach or bowel may take place. After death also, especially in hot weather, considerable areas of the intestinal canal may be digested by their own juices. In days when nothing was yet known about toxins and antitoxins, the immunity to autodigestion was believed to depend upon the working of some mysterious vital force. It is a human foible to "explain" an enigma by the use

Pavy

of an equally inexplicable word! But when Pavy, having introduced the ear of a living rabbit through an incision into the stomach of a dog, found that it was digested just as if it had been cut off and swallowed in the usual way, the vital-force explanation had to be abandoned. —Well, we have discussed the conditions of existence at considerable length, and I think you will agree with me that it is by no means easy to find a satisfactory definition of life.

B.—I certainly never imagined it would be so hard to draw a sharp line between inorganic and organic nature.—But I am eager to know what wonders you will unfold to-morrow.

A.—To-morrow evening we shall consider the struggle for existence, and shall discuss how various useful adaptations have arisen.

SIXTEENTH EVENING

STRUGGLE FOR LIFE

Circumstantial Evidence

A.—We have now discussed the most important data which have led to the formulation of the theory of descent. Our own lives are too short for us to be able to follow the process of the transformation of species. The foundation of the theory of descent therefore depends mainly upon circumstantial evidence, but you will agree with me that circumstantial evidence has seldom been more convincing than in this particular. As far as details are concerned, our views concerning the phylogenetic kinship of the world of organisms may undergo many changes ; but the theory of evolution as a whole, the belief that the development of species has proceeded from simpler to more complex forms, may be regarded as proved. It is another question altogether, what have been the causes of the gradual transformation of organic types. The most comprehensive attempt at an explanation has been that given by the Darwinian theory of natural selection. Darwin's teaching is rooted in the opinion that those organisms best adapted to the environing conditions have the best chance of survival in the struggle for existence, and therefore the greatest likelihood of transmitting their individual peculiarities to posterity. As early as the years 1831 to 1836, during the voyage of H.M.S. " Beagle " under the command of Captain Fitzroy—a voyage of exploration and research which Darwin accompanied as naturalist, being twenty-two years of age when the expedition started —the great investigator's epoch-making ideas concerning organic evolution already shaped themselves in his mind. But, being a critical investigator, he kept his theories to himself, while patiently collecting weightier evidence. Not until 1859, when he had rounded off his theory to his own satisfaction, did he publish it to the world in his famous book *The Origin of Species.* Since then, arguments for and against the validity and comprehensiveness of the theory of natural selection have been unceasing. Even to-day, biologists are still divided into the two great camps of the Lamarckians and the Darwinians.

Survival of the Fittest

Voyage of H.M.S. " Beagle "

The Origin of Species

B.—I thought the doctrine of evolution was now universally accepted by naturalists ?

Theory of Descent and Doctrine of Natural Selection

A.—You must not confound the doctrine of evolution with Darwin's theory of natural selection. It is impossible to protest too strenuously against any such confusion. Darwin's theory of natural selection takes the doctrine of descent for granted, and merely endeavours to show what forces have been at work in bringing about the gradual transformation of species. Even if Darwin's theory of natural selection had been shown to be erroneous, the validity of the doctrine of descent would not have been shaken. We should merely have had to admit that no one had yet succeeded in explaining evolution in terms of a uniform principle. In essentials, however, the theory of natural selection still holds the field. All that a straightforward critic can do, nowadays, is to point out certain weaknesses in Darwin's explanation, and to declare that other forces in addition to natural selection must, presumably, have been at work in effecting the gradual transformation of organic life.

The Dogma of the Constancy of Species and its Opponents

B.—If I am not mistaken, the earlier naturalists, led by Cuvier, were of opinion that animal species were inalterable natural units ?

A.—Yes, that is true in the main. Still, even before Charles Darwin, other investigators, above all Charles Darwin's grandfather Erasmus Darwin, but also Goethe, Jean Baptiste Lamarck, and Geoffroy Saint-Hilaire, were strongly opposed to the dogma of the immutability of species.

Notion of Species

B.—What is the precise meaning of the term species ?

A.—Although it is easy enough to give a strict definition of a species when we have only a few examples of it to consider, such a definition becomes increasingly difficult when we are presented with very many individuals, and especially when they are drawn from widely separated geographical areas. We always find some specimens which do not fit into our scheme, but diverge from it in various respects. Let

The Swan-Mussel

me give you one example of how vague the notion of species may be. Rossmässler distinguishes among the swan-mussels (anodonta) 6 varieties ; Küster, 26 ; other investigators speak of several hundred varieties ; whilst Lea says there are no varieties at all, but one uniform species. This diversity of views depends upon the marked variability of the specimens that come under observation. Even in closely adjacent lakes or ponds, we find swan-mussels which differ so much one from another in shape, size, and in the thickness and colour of the shells, that it is natural to regard them as distinct species. On the other hand, these ostensible varieties are linked by numerous transitional forms, so that the outlook of those who consider that they constitute one uniform species seems justified. Additional

Apparent Type (Phenotype) and Hereditary Type (Genotype)

uncertainty is introduced into the concept of species by the fact that apparent type and hereditary type are not necessarily coincident.

B.—You must please explain to me what you mean by apparent type and hereditary type.

A.—The hereditary type (genotype) represents, so to say, the sum of all the inheritable characters anchored in the germ-plasm ; those which, under like environmental conditions, manifest themselves more or less alike in all the members of the species through successive generations. But when environmental conditions change, the apparent type (phenotype) may be modified in such a way that individuals arise which, in numerous respects, differ so much from the stock that they might be regarded as new species. As long as these changed conditions remain at work, such new qualities appear in successive generations. Nevertheless, they need not have become hereditarily fixed in the germ-plasm. As soon as the old conditions are re-established, the offspring revert to the hereditary type. Thus the apparent type of any species may be regarded as the joint outcome of the working of hereditary factors and of environmental influences upon the developing organism. I feel sure you must

Dwarf Trees

have seen the lovely dwarf trees produced by the Japanese, plants whose growth and shape have been profoundly modified by prolonged starvation. But if you take seed from such a dwarf tree and plant it under natural conditions, there will result a tree of normal shape and size.

Varieties

B.—Of course I am familiar with the occurrence of individual variations, so familiar that I have come to take it as a matter of course. Among human beings, no child resembles its parents in every detail.

A.—As you say, each one of us has individual traits in addition to those common to us as members of a species. Besides, since, among the higher organisms, creatures that are the outcome of sexual congress always owe their existence to the co-operation of two individuals, they exhibit characters inherited from both parents. Speaking generally, these individual or fluctuating variations are not extensive. They diverge a little to one side or the other from a central point, the specific type. If, however, for unknown reasons, such deviations should occur in a particular direction for many generations and be inherited, then individuals would arise diverging so greatly from the parent stock that we should have to describe them as members of a new species. Do you understand that I am talking hypothetically ? Should the hypothesis be justified, then varieties claim our special interest as the starting-points for the origin of new species. If we could discover the causes which lead to the production of varieties, we should have taken a long step towards solving the riddle of the origin of species.

DOMESTICATED ANIMALS

B.—I suppose that was why Darwin paid so much attention to the history of domesticated animals ?

A.—Yes, you are right. Nowhere do we find so manifest an inclination to the formation of varieties and new races as in our domesticated animals and plants. It seems incredible that naturalists should have ignored this matter for so long. They actually regarded it as a desecration of science to devote attention to these " unnatural " products of human selfishness. Yet all the time, the history of domestication was a colossal, though unconsciously performed, scientific experiment. Just as the chemist and the physicist unhesitatingly apply to nature at large the experience gained in the laboratory, so are we justified in applying to animals in a state of nature the experience that has been gained during domestication of animals and plants. The fact is, however, that most of our domesticated animals have been companions of the human race for so long that, with few exceptions (the ostrich is one of them), only tradition and inference can tell us anything about the beginnings of domestication. In the case of very few domesticated animals do we know with certainty from what wild stock they were derived. It may be taken as proved that the original progenitor of our domestic pigeons must have been the small and graceful rock-pigeon, or blue-rock (Columba livia).

STOCK FROM WHICH DOMESTIC PIGEONS WERE DERIVED

B.—The races of domesticated pigeons differ so greatly one from another that they could certainly be regarded as distinct species. Why, then, are they supposed to have all been derived from one stock ?

A.—If you allow the various fancy pigeons which have no resemblance to the blue-rock to interbreed freely, they always revert to the original type of Columba livia.

B.—Has the rock-pigeon died out, or does it still persist ?

A.—The rock-pigeon is still extant in the wild state throughout large areas of Europe, North Africa, and Asia. Occasionally stray specimens turn up in Germany, but they have not, so far as I know, been seen to nest in our country. In appearance they are very like our ordinary wood-pigeons, but are distinguished from them by their more graceful form and by the brilliant metallic colouring of the neck and breast feathers. In the natural state they live gregariously in big flocks. Indeed, only social animals are suited for domestication. Many of the habits of the rock-pigeon have been transmitted to their tame descendants. Like these, rock-pigeons are poor nest-builders, constructing, in inaccessible crags, a roughly made nest put together from dry twigs, straw, and fibres of plants. The clutch consists as a rule of only two eggs. Another characteristic of the rock-pigeon is its disinclination to settle on trees, its peculiar way of nodding its head as it walks, the practice of flapping the wings loudly, and the way of soaring high in the air in dense flights. But, for all these resemblances, the divergences of our fancy pigeons from the original stock are more conspicuous.

B.—By what witchcraft has man succeeded in producing out of this one stock such different races as carriers, homing pigeons, tumblers, pouter pigeons, fantails, and numerous others which, to my way of thinking, differ from one another much more markedly than a rabbit does from a hare or a nightingale from a bastard nightingale (Sylvia philomela)? As you know, I am myself a pigeon fancier, and have been able to observe how, when crossing with other races is prevented, a particular breed of pigeons reproduces itself with the same steadfastness as a natural species. On the other hand, a pigeon fancier who has some definite end in view, can often achieve it in the course of a few generations. There is scarcely any part of the body which cannot be varied at will. Even mental qualities, which must depend upon the minute structure of the brain, can be affected by purposive breeding. This is proved by the existence of tumbler pigeons.

THE BREEDER AS CREATOR

A.—Your experience as a pigeon fancier must have given you an inkling of what I am driving at. Probably most of our domesticated pigeons owe their peculiar qualities to chance, to unconscious selection in the first instance. The breeder was struck by some quality or peculiarity which he wanted to emphasise, and, by breeding only from types which exhibited this to a marked degree, he pushed it to an extreme. Suppose the pigeon fancier wants to produce a carrier, a bird with the beak and eye-wattles enormously developed. How must he set to work? At first, he chooses, out of his stock, birds in which these qualities are most strongly developed, and separates them from the others. Since such individual peculiarities are, as a rule, markedly inherited, and since the offspring exhibit more or less a sum of the characters of both parents, in successive generations, by selection for this character, it will become more and more marked. If purposive selection be rigidly carried out for several generations, the pigeon fancier will secure a type which comes more and more closely to resemble the ideal he has in mind. But perhaps he is not yet satisfied with the result. He wants his carrier to have a particular colour. What is he to do?

EXTERNAL DIFFERENCES AND INTERNAL CONFORMITY TO TYPE

BREEDERS AIM AT PRODUCING WHAT THEY WANT

B.—He follows the same method, and only breeds from those of his carriers which exhibit most markedly the colour he desires.

A.—Yes, thus he will gradually produce a " race " which in aspect diverges very widely from the original stock. In general, the production of new races, therefore, is not effected by crossing (although crossing can lead to new races, the bull-terrier being a breed produced by crossing terriers and bull-dogs), but by the patient selection, for many generations, of variations in the direction the breeder is interested in. Of course only such parts and qualities as are outwardly observable can be subjected to this deliberate selection.

B.—I suppose that is why the domesticated animals, much though the races differ in appearance, resemble one another so strongly in internal structure?

A.—Certainly, for purposive selection (being directed, as aforesaid, only towards the development of outward characteristics in which the breeder is interested) has no effect upon the internal structure of the body. The same applies, of course, to plants. That is why the various races of strawberries and gooseberries have flowers and leaves so much alike, only the fruits being distinguished one from another in appearance and taste. It is otherwise as regards the various kinds of cabbage, for in their case men have not been interested in the flower or the fruit, but only in the qualities of the edible leaves, which therefore differ so much in the different races. In tulips and other garden flowers, on the other hand, it is the flowers that differ so much in colour, shape, and size, while the leaves are often scarcely distinguishable. Among the various races of silkworm, the caterpillars, the pupæ, and the full-grown insects are extraordinarily alike, the work of the breeder having been concentrated upon producing differences in the silken cocoon, in which he was mainly interested. What extraordinary differences artificial selection can bring about, may be illustrated by a few examples. The tail-feathers of the Japanese phœnix may attain a length of 12 feet or more; good layers, such as Wyandottes, Hamburgs, and Plymouth Rocks, will lay as many as 200 eggs a year; the extraordinary amount of milk produced by many cows has previously been mentioned. The Toulouse goose can attain a weight of 30 pounds, and the merino sheep, especially the electoral, has as many as 6000 hairs per square centimetre of skin, while sheep of ordinary breed have barely 1000.

Luther Burbank

B.—An artist in this domain of artificial breeding was Luther Burbank, who produced spineless cactuses, the Burbank rose which blossoms all the year round, the white blackberry, and (perhaps the most famous of his products) the stoneless plum.

Some Qualities and Characteristics easier to change than Others

A.—In his breeding experiments, Burbank did not only produce practical results, but made some extremely interesting theoretical observations. In his memoirs, he writes: "If we wish to change the nature of a plant or the nature of a human being, we must, first of all, take into account the length of time for which the particular hereditary character we want to get rid of has existed in the stock. It is comparatively easy to change the colour of a flower, but far more difficult to change the root, the number of leaves in the calyx, or the shape of the leaves. For colour was not acquired until the other qualities had already been fixed by heredity. Colour is a mere outward embellishment, whereas the whole life-history of the plant has perhaps undergone only trifling changes in structure and form during its acquirement. The poppy had few rigid hereditary qualities, and therefore it was easy to produce it in the most diversified shapes and colours, tall or short, yellow or red, with large flowers or small. The cactus, on the other hand, which for thousands of generations has had to struggle fiercely for existence, has its qualities deeply ingrained, and shows very little inclination to vary from the norm." Perhaps similar reasons explain the various phases of phylogenetic development which we were discussing on our third evening. The marked variability shown by new species that appeared early during the history of life in the world was probably dependent upon the fact that hereditary qualities had not yet been firmly anchored in them. But when the genes have become strongly fixed, the tendency to variation declines.

CORRELATION OF GROWTH

B.—When discussing the transformation of the reptilian jaw into the mammalian jaw, you showed how notably interdependent are various parts of the body, and how the transformation of one organ will necessarily entail changes in other parts.

A.—I am glad you have brought that up in this connexion. In the practice of artificial selection, the breeder is seldom able to modify only one character at a time. Often, without his wishing it, other parts of the body become simultaneously modified. If, taking a pair of our ordinary domesticated goats to start from, we tried to produce in them the huge horns of a steenbok, far-reaching transformations in the whole structure of the body would be involved. If bigger and heavier horns are to be supported, the roof of the skull must be greatly thickened, and the muscles of the neck must be strengthened. This would need an enlargement of the bony origin and insertion of these muscles. The spines of the cervical and dorsal vertebræ would have to become longer and thicker. Furthermore the bones and muscles of the fore limbs would have to become adapted to the greater load, which would necessitate changes in the blood-vessels and nerves supplying these limbs. Every organism may be said to be in a condition of unstable equilibrium, so that any change in one organ will bring about changes in other parts. Of course this correlation of growth has a good deal to do with the origin of new species and races, and has also to be taken into account in the work of artificial selection.—Now let me ask you a question. What factors must co-operate, if new races are to be bred?

B.—First of all, the bodily and mental qualities of the parents must be transmissible by inheritance to the offspring; consequently, there must be individual variability; and thirdly, there must be a purposive selection.

A.—Yes, you have understood what I was driving at. These three factors are the alpha and the omega of artificial selection. If only one of them were to fail to operate, the formation of a new species or race would be inconceivable. Darwin, working from the experience made in artificial breeding, drew the bold inference that the same causes which have led to the formation of races among our domesticated animals must have been operative in nature to bring about the gradual transformation of types in the organic world and what he called the origin of species.

B.—But in that case only an almighty creator could take the place of the human breeder?

Natural Selection

A.—In Darwin's view this part was played by what he called "natural selection", the "struggle for existence" promoting the "survival of the fittest". This natural selection, although it works very slowly, and takes thousands of years to achieve what man can achieve in a few generations, is in other respects enormously superior to artificial selection. For, whereas man, in the domesticated animals, while producing qualities which are advantageous to himself, will often so greatly impair the vitality of the creatures concerned that most domesticated animals would perish but for man's care—by the struggle for existence those individuals are chosen to produce posterity, and those alone, which are best adapted to the conditions of existence. That explains the progressive advance of living creatures and their ever completer adaptation to the conditions of existence.

B.—Is there any definite proof that all these three factors are actually at work in nature?

A.—No proof is needed that heredity is as marked in wild as in domesticated animals. In the former, no less than in the latter, the young, but for minor individual variations, are images of their parents. Variability is harder to demonstrate under natural conditions.

Variability

B.—If I call to mind the chaffinches or swallows I have seen, I cannot remember that one bird differed in any important respect from another.

A.—That is only due to a lack of training. Whereas the individual peculiarities of the members of our own race strike us instantly, and we recognise acquaintances after we have not seen them for years, if you go to a country inhabited by an alien race of an unfamiliar type you will at first find it difficult to distinguish one individual from another. Nearly all travellers to the Far East notice this among the Chinese or the Japanese. To begin with they can hardly detect even differences of age or sex, unless these are indicated by differences of dress. Still less would you find it possible to notice individual differences in a flock of sheep. Yet an Australian shepherd knows every one of a herd of a thousand individuals. Long practice sharpens the attention to trifling differences.

B.—But these individual differences are so small that I do not see how they could give an animal any advantage in the strug for existence.

NUMBER OF DORSAL VERTEBRÆ IN HERRINGS

A.—You are mistaken in thinking the individual variations to be so small. There may be considerable variability even in important systems of organs. Heincke, for instance, making a careful study of the common herring, has shown that the number of dorsal vertebræ varies between 53 and 58. We have already considered the varying length of the human cæcum. Thus variability is proved to exist, as the second necessary factor for natural selection.

B.—What about the third factor, the struggle for existence, which is to act as selector ?

OVER-POPULATION

A.—As I have already told you, animals and plants, without exception, produce many more reproductive cells than can ever ripen. In those organisms which have differentiated sexes, as a rule of each pair of parents only two offspring grow to maturity and achieve reproduction. There is no room for any more. If all the germs of life produced by an animal were to become mature and conjugate, then the earth would soon prove too small to provide space and nourishment for this one species.

B.—Surely you are exaggerating ?

THE CHESS-BOARD

A.—By no means. Don't you remember the story of the oriental despot, who, when a learned man had done him a service, promised to grant any boon that should be asked. The learned man requested the prince to give him as many grains of wheat as would be required if, taking a chess-board, one grain was put upon the first square, two upon the second, four upon the third, and so on, doubling, until every one of the 64 squares had been dealt with. The prince smiled at this modest request, but when he told his treasurer to comply with it, he found that all the wealth of the Indies would not suffice. To provide the supply for the twenty-first square, a million grains of corn would have been needed ; for the forty-first square, a billion ; and for the last square, wheat enough to cover the whole surface of the earth with a thick layer would have been required. This is a simple process of doubling. Yet more fantastic would be the increase of organisms if all the reproductive cells conjugated and survived.

ELEPHANT AND COMMA BACILLUS

An elephant does not become sexually mature until about the age of thirty, and remains capable of reproduction until about the age of ninety. Since the cow-elephant carries her young for nearly three years, and cares for it for a great many years after birth, a pair of elephants in the course of their life produce on the average about six young. Assuming that the mean duration of life of an elephant is about a hundred years, then one pair of elephants in seven and a half centuries would have about nineteen million descendants. Now let us take an instance from the realm of the minutest organisms. Under favourable conditions, the comma bacillus, the exciting cause of Asiatic cholera, divides every twenty minutes. In the course of one day, therefore, a single comma bacillus can produce the formidable number of 1600 trillions of offspring. According to Fischer's calculations this quantity of comma bacilli would weigh about 100 tons. As you see, a very large laboratory would be needed to carry on an experiment in which a comma bacillus were to be allowed to reproduce itself to the full of its capacity for twenty-four hours.

B.—Never before have I grasped the significance of these reproductive powers.

NUMBER OF INDIVIDUALS OF A PARTICULAR SPECIES IN A SPECIFIED AREA

A.—Fortunately for us, there is an obstacle in the way of such unrestricted multiplication. Long experience has shown that, in a specified area, strict limitations are imposed upon the number of individuals of a particular species that can live there. However great the transient variations in that number may be, in the course of long periods of time we find that the average is the same. Among the various animals and plants of a circumscribed geographical area, there obtains a similar correlative equilibrium as obtains among the organs of the body. A presupposition for the maintenance of this equilibrium is, of course, that the conditions of existence remain unchanged. Pestilence, famine, inundation, prolonged periods of exceptional cold or of drought, can, naturally, decimate a species, or even annihilate it. On the other hand, we find that both animals and plants, when introduced to new and favourable conditions, can multiply with terrific speed. When rabbits were first introduced from Europe into Australia, no one anticipated what a plague they would become in their new habitat. Having no enemies to keep them in check, the rabbits multiplied so rapidly that the government was compelled to offer special premiums for their extermination. Bovines and horses, like the elephant, are animals that reproduce slowly; but, nevertheless, the huge herds which people the vast prairies of America are the descendants of a few specimens introduced by Europeans. The plains of La Plata are to-day covered by artichokes and by specimens of another variety of thistle, which have crowded out indigenous growths. These plants, likewise, were introduced from Europe in comparatively recent days. Of course, the rate of reproduction increases as the number of individuals in an area does so. One might think, therefore, that multiplication would soon pass beyond bounds. Still, even for the new and more favourable conditions, a possible average figure is soon attained, and the conditions of existence impose an insuperable obstacle to any further multiplication.

B.—This signifies, then, that, as soon as, in any area, such a balance has been achieved, from each couple of parents, on the average only two descendants can, in their turn, effect reproduction. A mammoth tree (Sequoia gigantea), which lives thousands of years, need produce only one seed during its long lifetime, if this could be sure of growing into a new tree.

A.—On the average, that is so. Inasmuch as the fertility of any species is, within certain limits, a fixed magnitude, we can, from the foregoing data, readily calculate how many of the germs of life must be destroyed before reproducing themselves, so long as no change takes place in the constitution or circumstances of the species. Thus, of the six young to which a pair of elephants on the average give birth, four must perish before attaining sexual maturity. Much higher is the rate of destruction in the case of crows. Assuming that a pair of crows produce five young birds twice every year, for 20 years in succession, of these 200 offspring, 198 are foredoomed to premature death. But even crows are among creatures with a

Stupefying Figures

rather low fertility. A carp produces annually round about 250,000 eggs, and can continue to do so year after year for 50 years. Its potential offspring would thus amount to round about 12,500,000, of which 12,499,998 must perish, either as ova, or as embryos, or as young fish which do not reach sexual maturity.

Number of Offspring

B.—It seems barely credible that so many of the germs of life are continually being destroyed. Nor can I understand why, in the case of animals with a high rate of reproduction, millions of the offspring must die prematurely, whereas only a few die prematurely in the case of creatures with a low rate of reproduction. If the struggle for existence were really as murderous as is commonly supposed, then none but organisms with an enormous fertility could be able to maintain themselves in existence, whereas all living creatures that produce few offspring would speedily become extinct.

A.—The rate of reproduction is strictly dependent upon the dangers to which the offspring are exposed during developmental phases. In animals among which the parents keep careful watch over the upbringing of the young until these latter are able to care for themselves, the risks threatening the brood are naturally much smaller than in the case, for instance, of sea-urchins, which are content to discharge their reproductive products into the sea. Many parasites, such as the liver-fluke, have, before they can become sexually mature, to pass through phases in the bodies of different animals as hosts. Under such conditions, the young are of course exposed to terrible risks. Scarcity of food and abundance of enemies also play a devastating role. Caterpillars and butterflies are mainly kept down by insectivorous birds, also by ichneumon flies, predatory flies, and numerous parasites, which work havoc among them. To keep plagues of caterpillars in check, scientific agriculturists have of late actually engaged in the breeding of appropriate ichneumon flies. After a severe winter, or after unfavourable food conditions, thanks to which the natural enemies of grubs and their parents have been extensively destroyed, there is usually, in the ensuing year, a marked increase in the plague of caterpillars. But this excessive multiplication of caterpillars soon leads automatically to its own cure. Since the food supply of the birds, the ichneumon flies, etc., has been so greatly increased, they, in turn, multiply abundantly, and thereupon the plague is stayed. Thus, in the course of the years, the indicator on the scales swings continually this way or that, and does not remain permanently inclined to one side or to the other. Seldom, however, are the factors which keep the numbers of a particular species in check so obvious as in the cases I have just been describing. The fertility of pansies and of purple clover depends, in a complicated way, upon the number of cats.

Clover and Cats

B.—Surely you are joking?

A.—No, not at all.

B.—I cannot guess at the connexion of which you speak.

A.—As you know, in the fertilisation of many flowers, insects play a supremely important part as transferers of pollen. Quite a number of flowers are so closely adapted to the services of a particular kind of insect, that members of this latter species and no other can dust the stigma with pollen. Unless the stigma is so dusted, no seeds are formed. Darwin's investigations showed that the transference of pollen in the case of purple clover and of pansies was almost exclusively effected by humble-bees, no other insects having a sufficiently long proboscis to reach the nectar of these flowers. Under normal conditions, 100 purple clover flowers produce 2700 seeds, whereas the same number of clover flowers which Darwin protected from the visits of humble-bees did not produce a single seed.

B.—That I can understand. But what on earth have cats to do with humble-bees?

A.—Nothing directly, but indirectly a great deal. The number of humble-bees in a specified area is mainly dependent upon the number of field-mice, creatures which, in their subterranean wanderings, plunder the nests and combs of many humble-bees. You cannot deny that cats are the most efficient destroyers of field-mice, whose numbers they hold in check. Of course field-mice have other enemies, such as the common buzzard, the owl, the stork, and the weasel. Still, the fact remains that, in this circuitous way, the fertility of purple clover is in large measure dependent upon the abundance of cats in a neighbourhood.

B.—What laborious observations must have been necessary to trace the complicated paths followed by nature. All the same, the course of Darwin's ideas is not yet clear to me. Admitted that different species keep one another's numbers in check, I do not see how it follows that this struggle which may lead to annihilation can, by natural methods, bring about the breeding of higher types.

Breeding of Higher Types

A.—You are right. It cannot do so spontaneously. A positive natural selection can only occur when, among the numerous progeny of a species, only those individuals best adapted to the conditions of existence survive and transmit their individual peculiarities to their descendants. With this proviso, and on the assumption that individual variations are inherited, natural selection must, in the long run, inevitably lead to a gradual perfectionment of the world of organisms.

TELEOLOGICAL VIEW OF NATURE

Until Darwin's theories became generally known, most biologists believed that seemingly purposive organs and the adaptation of organisms to their environment could only be explained on the hypothesis that a purposive principle is at work throughout nature at large. This teleological view of nature was rooted in the belief that the creator of the world had arranged everything in it in such a way that we human beings were compelled to regard his actions as purposeful. Just as a machine-designer begins by drawing the separate parts upon paper, before the machine is assembled in concrete reality, so it was supposed, the creative world-spirit began by thinking over the plan of his work and then uttered his " Let it be ! " The human engineer or machine-designer, being imperfect, could make mistakes in his calculations ; but it would be blasphemous to ascribe faulty construction to a divine creator. Nevertheless, from the biological outlook, we note numerous imperfections in natural contrivances. The expedients to which nature has recourse in the construction of living organisms seem, in many cases, to be the most casual contrivances when compared with those which are thought out in advance by the human mind. Consider what we were talking about just now —the thriftless expenditure of the germs of life. Of the millions of ova that are produced, only a very few are chosen to fulfil what seems the supreme purpose of an ovum, that of reproduction. The failure to achieve maturity is the rule, and reproduction a rare exception. " If a man ", writes Friedrich Albert Lange, " in order to shoot a hare, were to fire a million shots at random ; if he, wishing to enter a locked room, were to buy 10,000 keys haphazard, and try them all in the lock one after another ; if, wishing to build a house, he were to build a townful of houses and leave the superfluous ones to be ruined by the wind and the weather—it would not occur to any one to regard his conduct as wonderfully purposeful, or to suppose him to be animated by supreme wisdom." But is nature's method any other than the foregoing ? Unquestionably, various living organisms, contemplated in isolation, are of a structure surprisingly well adapted to their respective surroundings. They seem eminently purposeful. Very different is it, however, when we contemplate organic nature as a whole. The struggle among the species, the fact that every living animal must destroy other living creatures in order to exist, cannot be fitted into a general teleological scheme. It was Darwin's pre-eminent service that he was the first to direct attention to the squandering of the germs of life, and to suspect, in this seemingly blind play of chance, the working of some

FRIEDRICH ALBERT LANGE

VALUE OF THE THEORY OF NATURAL SELECTION

deeper law. The theory of the natural selection of the most efficient elements as an outcome of the struggle for existence, rendered it possible to refer the origin of purposive organs, the origin of adaptations, to natural causes, and to subsume them under a general law. As to whether Darwin's bold hypothesis provides in every case a satisfactory explanation, and as to whether the theory can be maintained in its original formulation—these are matters to be considered by and by. Upon one point I may insist at this juncture, namely that the theory of natural selection is valid only in its application to a part of organic phenomena. The ultimate enigma of the vital process remains unsolved. The theory, if there be no flaw in the assumptions upon which it is based, can provide us with an explanation of the progressive increase in adaptations ; but it takes the vital process for granted. Yet the most primitive organisms, which perhaps originated by spontaneous generation, must have been purposively organised from the start, or they could never have maintained themselves in existence. Had not these primordial creatures been endowed with the capacity of reacting purposively to environmental influences, they would have perished as soon as formed, without being able to reproduce their kind. Darwin's theory provides no explanation for this fundamental purposiveness of all that lives.

So much for to-night. To-morrow evening I shall try to show you how the struggle for existence works, and to what extent it is capable of explaining the perfectionment of adaptations.

SEVENTEENTH EVENING

PHENOMENA OF ADAPTATION

A Hare in its Form

Protective Colouration

Adaptation of Hare to Snowfield

A.—No doubt when out shooting with only an ill-trained hound to help you, you must have almost stumbled over a hare, which you never noticed until it jumped up after you had passed. Crouching in its form, puss allowed the enemy to come quite close, trusting in the colour of its fur (brownish black interspersed with yellow hairs) which made it practically invisible amid the stubble. This protective colouration has certainly been one of the factors enabling hares, though so fiercely pursued by men and beasts of prey, to maintain themselves in the struggle for existence. But the colouration I have just described is only protective in the summer-time, and evil days begin for hares as soon as the snow lies on the ground. Their enemies can see them from a great distance. If a new Ice Age were to arise in Central Europe, or if the snow were merely to lie on the ground for three parts of the year, conditions of existence for our hares would become far more unfavourable than they are. In such circumstances, those hares would have the best prospect of survival, the best chance of escaping their enemies, whose furry coat was lightest in colour, contrasting least with the snowy landscape. They too, of course, would occasionally fall a prey to their enemies, but, on the average, they would have better chances of survival. More light-tinted than dark-tinted hares would attain sexual maturity and would transmit their individual peculiarity in this respect to offspring. Should the process continue for a sufficiently long period, through the working of natural selection it would result that only light-tinted hares would persist.

B.—But colour harmonising with the environment is not the only means of protection. A dark-tinted hare which was by nature more timid or was able to run quicker than its fellows, would perhaps have better chances of escape than a white hare which was slow of movement and less on the alert.

A.—In due course we shall consider the objections that might be raised to your contention, but at the moment I am concerned only to make the positive aspects of the theory of natural selection plain to you. I will ask you, therefore, to accept my presuppositions for the nonce. Among the light-tinted specimens, natural selection would remain to work, so that the lightest tinted among them would continue, on the average, to have a better chance of escaping their enemies. If the cold should persist for a sufficient number of years, there would, in the end, be only white hares remaining.

B.—Your example seems to me somewhat far-fetched.

Arctic Fauna

A.—I am not presenting you with arbitrary theories, but with the data of experience. In the polar regions, and in the high mountains of our own land, we find among common hares a white variety, the snow-hare. Within the arctic circle, there are not only white hares, but also white foxes.

B.—But how can the theory of the origin of white foxes by selection be valid, seeing that man is the only important enemy of the fox, and that man has not, until recently, been engaged in destroying foxes within the arctic circle ? The arctic fox had had his white coat long before human trappers were at work in those regions on the hunt for his fur. I cannot see, therefore, why the arctic fox needed protective colouration.

A.—I will concede to you this much, that the fox is not so widely threatened as the hare. Still, dark-coated foxes would be visible on the snowfields at great distances, so that the prey they hunt would be given ample warning of their approach. Beyond question, red foxes or dark foxes on a snowfield would find it difficult to gain a livelihood, and this would be sufficient reason for the working of natural selection in order to whiten their coats.

B.—True, I had not looked at the matter from that side.

Artificial and Natural Selection

A.—Whereas a human breeder is usually modest in his aims, and tries only to cultivate one particular characteristic in his charges, natural selection can get to work simultaneously upon numerous characters. It will not be content to select merely the lightest tinted animals, but also, among them, the swiftest, the most intelligent, the most vigorous—in a word, individuals which are in every respect superior to their fellows. Nature uses the same means as man, but (from the Darwinian outlook) nature greatly excels man in skill.

B.—Above all things, certainly, nature has a great advantage over man as breeder, inasmuch as nature has millions upon millions of years at her disposal.

A.—Incontestably. On the other hand, it cannot be denied that the human breeder, who deliberately concentrates his attention upon one particular quality, and selects, for breeding purposes, only those males and females in whom that quality is especially well marked, can achieve results far more speedily. Under natural conditions, it must again and again happen that an exceptionally light-tinted doe-hare is covered by an exceptionally dark-tinted buck-hare, thus interfering with the process of selection. But I do not intend to speak now of objections or difficulties. The indubitable fact is that, in the numerous kinds of animal that dwell in the far north, a white colouration predominates. You need think only of polar bears, snow-owls, and ptarmigan.

WHY IS THE SABLE DARK BROWN?

B.—If a white colouration gives advantages in the struggle for existence, I should have expected that, in the course of millions of years, all animals inhabiting the polar regions would have turned white. But the sable, with its dark-brown fur, is also an inhabitant of the extreme north. Is not that a flaw in your theory?

A.—You must always take the habits of the creature into consideration before you decide such questions. The sable is predominantly arboreal, seeking its prey among the tree-tops. For such an animal, a white coat would be disadvantageous rather than useful. Upon the dark branches, this big creature, were it white, would be extremely conspicuous, whereas the dark-brown fur makes it much less conspicuous.

WINTER-COAT AND SUMMER-COAT

Still more striking is the colour-adaptation of many inhabitants of the temperate zone, which vary their tint as between winter and summer. Thus, two of our native weasels, the great weasel or ermine (Mustela erminea) and the lesser or common weasel (Mustela nivalis), have in summer a bright brown coat, and in winter a white coat.

B.—I did not know that the weasel turned white in winter.

A.—I think you did know it, but you did not know that what in our own country we call an ermine is the same beast which in summer you know under the name of weasel. The most remarkable fact is that in the southern and sunnier parts of Europe the weasels retain their reddish-brown summer-coats throughout the winter. A similar change of colour to that undergone by ermines, weasels, and stoats (whichever you please to call them) is undergone by Alpine hares and ptarmigan; and the arctic fox and the snow-owl likewise turn darker in summer.

DESERT-DWELLERS

B.—I suppose you account in like manner for the fact that desert regions and jungles are mainly peopled by yellow and yellowish-brown animals?

A.—Yes. In most cases, too, the protective colouration is reinforced by peculiar stripes and other markings. The dark stripes on the yellowish-brown coat of the tiger, make this creature almost invisible in the jungle. Similar dark stripes or spots upon a sandy-coloured ground are seen in numerous other inhabitants of the torrid zone, such as the zebra, the giraffe, the okapi, the leopard, the panther, and the cheetah. But lower animals, too, offer abundant examples of the same thing. You know the sandy-coloured sandviper (eryx), the cobra, and the gecko; also many kinds of insects, especially desert grasshoppers and locusts. Most investigators believe that the tint of these animals is a protective colouration produced by natural selection.

DESERT GRASSHOPPERS

B.—Still, there are exceptions among desert grasshoppers and locusts, for redwing locusts have bright red under-wings that make them visible at a great distance. How do you explain this striking colouration, which must make the welcome titbits so conspicuous to birds. It does not seem to me to harmonise with the theory of natural selection.

A.—You are mistaken. The instance to which you refer is a remarkably striking case of protective adaptation. The redwings in question only show their brilliant under-wings when flying. Doubtless the bright red attracts the attention of birds, which stoop to seize their prey, but thereupon the locust settles on the desert sand, folds its wings, and has disappeared as if swallowed up by the earth. The

LEADING ENEMIES ASTRAY

bird, which has been pursuing a fiery-red insect, continues to seek for this, overlooking the sand-tinted creature crouching motionless under its very eyes. Such, at any rate, is the explanation of the Darwinians. The bright colouring of the under-wings of the death's head moth, catocala, and other noctuids, can be similarly accounted for. This explanation is supported by the fact that in moths, in which, when they are at rest, the upper-wing usually covers the under-wing, only the under-wings are brightly coloured, whereas the upper-wings have a protective colouration. In butterflies, on the other hand, which, when at rest, usually have the wings apposed above the back, so that only the under-side of both pairs of wings is visible, the upper side is brightly coloured, but the whole of the under-side of both pairs of wings is protectively tinted. You cannot fail to have noticed how many creatures that live in the grass or on leaves —such as ordinary grasshoppers, the caterpillars of many butterflies, and the larvæ of other insects, also frogs and lizards—are green.

WHY ARE NOT ALL BIRDS GREEN ?

B.—Of course ; but there are many exceptions. Apart from the green woodpecker, the greenfinch, the bunting, the siskin, the serin, some of the tomtits, the golden oriole, and various wood-wrens, I can scarcely think of any green birds in our German homeland.

A.—The exceptions to the rule that dwellers among leaves are green can easily be explained. In our climate, the trees and the twigs bear no leaves for half the year, so that a green colouration would only be of dubious advantage to the birds. In the tropics, where the forests are green all the year round, there are many more green birds. In the case of many water-dwellers, transparency takes

TRANSPARENCY OF MANY WATER-DWELLERS

the place of protective colouration. The sea-water is peopled by vast numbers of salps, medusæ, sea-slugs, and crustaceans, which go about their daily business almost as inconspicuously as if they wore a cap of invisibility. The ova and the free-swimming larvæ of many of the lower inhabitants of the sea are also protected by transparency.

Now I should like to mention another remarkable adaptation we find in many of the dwellers in the sea. Although the light of day cannot penetrate more than about 1200 feet below the surface, so that the depths are enveloped in perpetual night, the fishes, the cephalopods, and the crustacea of those regions have well-developed eyes.

B.—But if an organ becomes functionless, it atrophies, as the eyes of the cave-salamander and the mole have atrophied. How do you explain these exceptions ?

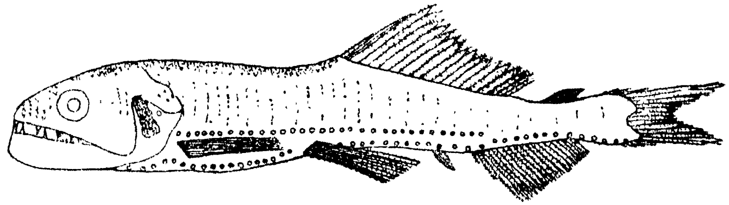

FIG. 74.—A DEEP-SEA FISH (BATYLYCHNUS CYANEUS) WITH LIGHT-ORGANS. (After BRAUER.)

The light-organs are indicated by the little circles that run along the lower part of the side.

LIGHT-ORGANS OF INHABITANTS OF THE DEEP SEA

A.—The explanation is simple. The inhabitants of the deep sea manufacture artificial light. Like our glow-worms and fire-flies, most of the dwellers in the deep sea are equipped with light-organs. These light-organs may be distributed all over the surface of the body, some of them being provided with lenses, reflectors, anti-dazzle equipment, and so on. Often they radiate coloured light. As far as we know, these coloured lights enable the members of a species to distinguish one another, and the males to find the females. This theory is supported by the fact that the kind and arrangement of the light-organs often differs in the males and the females. (See Figs. 74 and 75.)

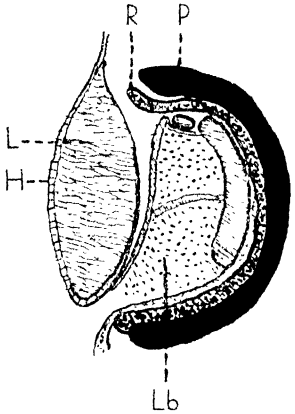

FIG. 75.—LIGHT-ORGAN OF A CUTTLEFISH (SEPIOLA INTERMEDIA). (Diagrammatic.)

H, epidermis ; L, lens ; R, reflector ; P, pigment-mantle ; Lb, light-bacteria, which dwell symbiotically in the light-organ and produce the light.

MIMICRY

B.—You have not hitherto said anything about adaptations which I have always heard spoken of as the main supports of the theory of natural selection ; I mean the imitation of some lifeless object by an animal.

A.—I was coming to that. We can distinguish two kinds of mimicry : the resemblance of many creatures to thorns, dry twigs, or leaves ; and the imitation of the members of one species by creatures which have no kinship with them. I will give you a few instances. In the Australian seas there is found a relative of our sea-horse, the rag-fish (Phyllopteryx eques), which lives among the seaweed, being hardly distinguishable there owing to its tint, and the peculiar rag-like processes which project from its body. The walking-stick insect (Xylina vetusta), known to every butterfly-collector, can, when quiescent, scarcely be distinguished from a dry twig. Many beetles

WANDERING LEAVES

resemble birds' dung. The wandering leaf, belonging to the family phasmidæ, looks, when it begins to fly, as if a leaf had suddenly taken on animal life. Among our native fauna there are plenty of examples. Underwings, Vanessa, and many other butterflies and moths, when quiescent, resemble dry leaves or the bark of trees, whereas when in flight, like redwing locusts, they have a brilliant colour. The classic example of such protective mimicry is

LEAF-BUTTERFLIES

the Indian leaf-butterfly, Callima parallecta, which, in repose, resembles a dried leaf down to the minutest details. Even the stalk and the veining are not forgotten. (See Fig. 76.) As Delage says, one gets the impression that the leaf must have been painted by a skilful artist. There are places which look as if the scales had been rubbed off, resembling mouldy spots upon the leaf, or areas where it has been gnawed by insects. No less common is mimicry in

VENOMOUS CREATURES AND THEIR IMITATORS

the narrower sense of the term, the imitation of one kind of animal by another. The model in such cases is usually an organism which is safeguarded against enemies by venomousness or by having an exceedingly nasty taste, whereas the imitator lacks these defences.

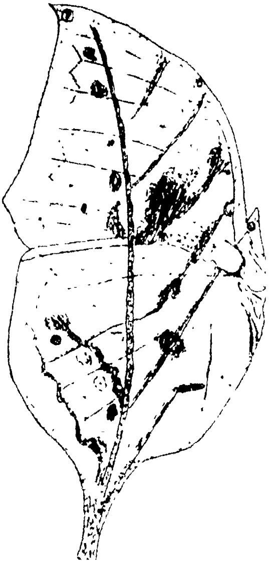

FIG. 76.—CALLIMA PARALLECTA, ONE OF THE INDIAN LEAF-BUTTERFLIES (After WEISMANN.)

When the insect is at rest, with the wings apposed behind the back, it mimics a dry leaf.

B.—Are there instances of this kind of mimicry in our part of the world?

A.—Certainly. Hornets, justly dreaded for their stings, are mimicked by a butterfly, the harmless hornet-butterfly. Humble-bees and other bees are imitated by various species of flies; wasps, by beetles; and ants, by spiders. In the forests of Guatemala lives the dreaded venomous snake Elaps corallinus, the coral snake, which is of a brilliant red colour marked by black stripes, making it conspicuous at a great distance. As a close associate it has a snake of another genus (Erythrolampus venustissimus) which resembles Elaps so closely that only an expert can distinguish the two. In North America we find a snake akin to the coral snake, Elaps fulvius, which deviates in colour to some extent from the coral snake; and these deviations are faithfully copied by certain non-venomous snakes of the same region. Even more amazing are cases of mimicry when the animals concerned belong to different classes of the animal kingdom. In the Indian Ocean, not far from New Pomerania, there is

Sea-Snakes and Fishes

a sea-snake, Platurus colubrinus, a venomous, strikingly coloured creature, several yards long, which serves as model for a predatory fish, Ophichthys colubrinus. Finally, let me give you an example

Heliconidæ and Pieridæ

from among the papilionaceæ. On the shores of the Amazon there are swarms of brightly coloured heliconidæ, fluttering among the bushes. Although their glaring tints would seem to expose them to the assaults of their enemies, only a very young and inexperienced bird will touch one of these heliconidæ, and will never take a second into its mouth, for these butterflies have so offensive a smell and taste that they are generally avoided. Among the swarms of the heliconidæ there are always fluttering about butterflies of a very different species, pieridæ, which lack this nasty taste and smell. But the pieridæ resemble heliconidæ in form and colour, and in the peculiar cumbrousness of their flight, so closely as to be exempt from attack. Plate reports a similar case from Ceylon. Papilio polytes, inhabiting that island, has females of three different shapes, only one of which resembles the males. Both males and females, however, are very like Papilio pammon. The second kind of females of Papilio polytes resembles Papilio aristolochiæ, and the third kind resembles Papilio hector, both of these latter having, like the heliconidæ, a disagreeable taste. Plate offered a number of specimens of Papilio hector among twenty other butterflies to a hungry calotes lizard kept in a cage. Within two hours the lizard had devoured all the other butterflies, while leaving the specimens of Papilio hector untouched. "They were, then, actually protected." Plate draws the conclusion that this protection would be extended to the Papilio polytes females that resemble Papilio hector and fly about among them.

B.—You speak in a sceptical tone. It seems to me, however, that the examples you have given make it impossible to doubt the great biological importance of protective colouration.

Has "Protective Colouration" a Selective Value?

A.—Nevertheless, Eimer and many other investigators bluntly deny the utility of protective colouration. I do not go so far as that, but a close study of the facts arouses many doubts in our minds. We are far too ready to look at such phenomena from our own anthropocentric outlook. Because one of the desert-dwellers has a sand-coloured coat, or because one of the phasmidæ resembles a dried twig so closely that we find it difficult to distinguish it from the twigs among which it is resting, it does not follow that these qualities are truly advantageous to the creatures in the struggle for existence, and still less that they were brought into being by selection.

B.—I do not see how the occurrence of the features in question can be otherwise explained.

CATOCALA NUPTA

A.—An example from our own homeland may make you realise that we need to be cautious in our judgment where such matters are concerned. The yellow underwing, Catocala nupta, resembles in tint and marking the yellow spots upon a wall overgrown with lichen. Carefully arranged in a museum, they seem to us amazing instances of protective colouration. But in natural conditions, this unruly creature has a preference for settling in spots with which it strongly contrasts.

B.—But surely the tint and markings of the great predatory cats of the tropics, thanks to which they melt into the surrounding jungle, must make it easier for them to approach their prey ; whereas gazelles, antelopes, giraffes, zebras, and jerboas must, by similar adaptations, often be unable to escape their enemies.

A.—However obvious that may seem, there is a catch in the reasoning. All the predatory felidæ are nocturnal hunters, their prowl for prey beginning when night falls and ending at dawn. By night, however, these big cats, like all other creatures, are grey. What advantage, then, can their protective colouration offer them ? In general, moreover, among these big cats, hearing is better developed than sight, so that, when hunting, they depend mainly upon their acute ears. Other beasts of prey hunt by scent. To them, likewise, protective colouration can be of little importance.

B.—Still, the protective mimicry of many insects must have a purpose.

PROTECTED AND UNPROTECTED SPECIES

A.—Here, too, we must be careful to avoid overstatement. If protective colouration really gave the animals concerned so great an advantage in the struggle for existence as compared with animals not similarly adapted, it would be hard to understand why these latter have not long since become extinct. At any rate one would expect to find that the protected species would greatly outnumber the unprotected, and would be far more widely distributed. The opposite is true, however. You know how quickly the eye gains experience, how readily a butterfly-collector can discover even the best adapted caterpillars in their protective environment. Speaking generally, the sense organs of predatory animals are far sharper than our own. A common buzzard can see a mouse from an altitude of over 300 feet. Do you think that such an enemy would be humbugged by a more or less superficial resemblance ? How, above all, can you explain the cases in which animals of one species mimic those of another inhabiting a widely distant geographical area ?

B.—I did not know that such mimicry occurred. Please give me an instance.

SEMNIA AND CARYATIS

A.—Gladly. In Brazil we find a butterfly Semnia auritalis, which closely resembles in every detail the kindred Caryatis viridis that lives far away in Cameroon. But the resemblance between Semnia and Caryatis cannot be anything other than the product of chance. In view of the vast number of different species, such occasional resemblances in aspect are likely enough. Every animal moreover must have a certain shape and a certain tint. Why, then, should not it occasionally happen, by chance, that a creature should resemble some dead object ?

B.—Your reasoning does not convince me, since it leaves too much scope for chance. Such instances as the mimicry of venomous serpents by non-venomous ones, or of the sea-snake by a fish which lives in the same waters, cannot have been brought about in any other way than by selection.

A.—Let us consider these two cases somewhat more closely. The fish ophichthys is so admirably protected by its size and its powerful bite, that it need hardly fear any enemies in its habitat. When hunting its prey, its close resemblance to the sea-snake must be a disadvantage rather than an advantage. But we do not need to appeal to chance in such cases. Presumably the resemblance is one of those phenomena of convergence as to whose causes we remain in the dark, but which are common enough.

CONVERGENCE

B.—Another technical term ! I am afraid I must ask you to explain what you mean by convergence.

A.—The occasional use of technical terms is unavoidable, since there is no vernacular word for many of the phenomena that come under scientific observation. By convergence we mean a resemblance between organs or organisms originally of a different kind, which have come to perform the same functions or are exposed to the same environmental conditions. In other words, we have to do with an outward resemblance that has arisen secondarily, thanks to adaptations that have occurred independently in the same direction.

B.—Your examples must be more concrete, please.

EYES OF CUTTLEFISH AND VERTEBRATES

A.—If you compare the eyes of cuttlefish and vertebrates, you will find a very remarkable similarity of structure. The eyes of both animals have a cornea and a lens, an iris—diaphragm, muscles for the accommodating of the lens to near vision, a vitreous body, and a retina. Nevertheless, these closely similar optical apparatus arose during embryonic life in utterly different ways. (See Fig. 77.) The eye of the cuttlefish, like that of other molluscs, is formed by an invagination of the epidermis, whereas the vertebrate eye is an outgrowth from the brain, which comes into contact with a proliferation

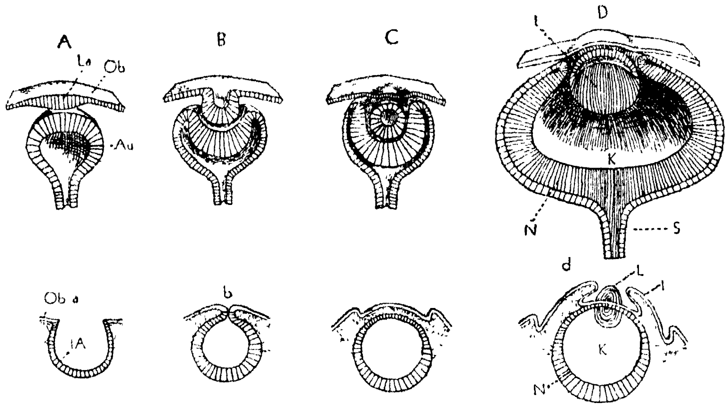

FIG. 77.—COMPARATIVE EMBRYOLOGY OF THE EYE; A, B, C, D, IN A VERTEBRATE; a, b, c, d, IN A CUTTLEFISH.

Ob, epidermis; La, rudiment of lens; L, lens; Au, ocular vesicle; K, posterior chamber; N, retina; S, optic nerve; IA, inner wall of the ocular vesicle; I, cutaneous fold which undergoes transformation into the iris. Whereas in vertebrates the greater part of the eye is formed by a protrusion (Au) from the brain, into which the epidermis (Ob) invaginates itself to form the lens (La and L), most of the cuttlefish's eye is formed by the ingrowth of the epidermis, producing both lens and retina, the latter subsequently becoming connected with the brain through the instrumentality of the optic nerve.

of epidermic and connective tissue-cells. Let us take another instance. Many of the fishes that live among coral reefs, though of different species, have strikingly similar motley tints. The cats, goats, sheep, cattle, and

Fauna of Angora and Tibet

dogs living on the elevated plateaus of Angora and Tibet are distinguished by the long hairs of their silky coats. Since,

Telescopic Eyes

as I have told you, the depths of the sea are only illuminated by the phosphorescence of the animals that dwell there, these creatures need powerful visual organs in order to discern one another. Consequently, among many of the dwellers in the deep sea, although belonging to very different classes of the animal kingdom, the eyes are tubular, the lenses being enormously elongated. Such telescopic eyes (see Fig. 78) are found in fishes, cuttlefish, and crustacea. I need

Ants and Termites

merely remind you of the ants and of the termites which belong to an entirely different order of insects, and how the social life of these creatures

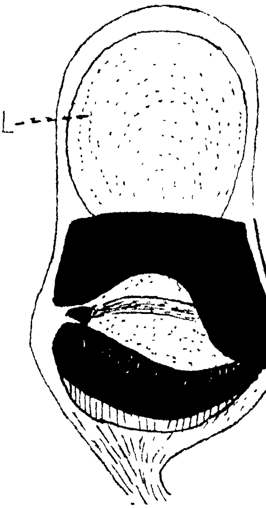

FIG. 78.—TELESCOPIC EYE OF A CUTTLEFISH.

L, the much protruded and greatly enlarged lens.

is so similar that the termites are popularly and erroneously spoken of as " white ants ". Both ants and termites keep and breed " cattle ", both of them collect leaves on which they grow fungi to feed their larvæ, and in both ants and termites the inhabitants of the community are differentiated into workers, soldiers, overseers, etc. Both among ants and termites we find other creatures living as guests in symbiosis, and even these guests have in large measure become adapted to their semi-parasitic life, so as to resemble one another in the respective cases. Yet these two kinds of insect State have come into being in utterly different ways. Let me give you another example. Both

FORAMINIFERS AND AMMONITES

among the unicellular foraminifers and among the ammonites (an extinct kind of cuttlefish) we find the same spiral arrangement of the chambers, because the excretion of the hard parts has occurred in both under the working of the same mechanical laws. Presumably the whiteness of animals that live in the arctic circle and the yellow colouration of those that dwell in the desert must be the outcome of convergence. It is natural enough to suppose that the working of similar external influences may result in similarity of aspect. The

EFFECTS OF TEMPERATURE ON LEMMINGS

example of the lemmings shows us that the colour of the fur is influenced by temperature. In their northern homeland, lemmings assume a white coat in autumn, but if kept in a warm room they remain grey throughout the winter. If taken out of a room and exposed to the cold, they begin to turn white within a few days.

B.—Do you then suppose that the mimicry of venomous snakes by non-venomous ones is the outcome of convergence ?

IMMUNITY OF SNAKE-EATING ANIMALS

A.—I do not go so far as to say that, but I cannot perceive any biological utility in such mimicry. Can you tell me of any snake-eating animal which distinguishes between a venomous and a non-venomous snake ? Snake-eaters are safeguarded by a constitutional immunity, and do not care whether the snakes they attack are venomous or not. With equal fortitude, the hedgehog of our own lands attacks

IMMUNITY OF THE HEDGEHOG

the harmless grass-snake and the poisonous adder, and does not suffer in any way by eating the poison gland of the latter. Our spiny friend is immune to the adder's bite, for its blood contains antitoxins which render the venom harmless.

B.—Can that be proved by experiment ?

A.—Yes. A guinea-pig bitten by an adder speedily dies. But if, beforehand, blood serum from a hedgehog be injected into the guinea-pig, it is temporarily immunised against the adder's venom. What I have told you about the hedgehog applies also to the mongoose and other snake-eaters. Thus the mimicry of venomous snakes by non-venomous ones does not save the latter from destruction by their enemies. As for man, the enemy of all snakes, he attacks venomous ones more zealously than the non-venomous. But presumably snakes had their characteristic colour and markings long before the appearance of man on earth.

B.—If adaptive colouration has no protective influence, how can you explain that many animals deliberately and ceaselessly adapt their tint to their environment?

A.—I do not explain it, because I don't believe that they do what you say deliberately and consciously, although it is true that their colour often changes to harmonise with that of their environment.

B.—You seem to me to be playing with words.

CHANGE OF COLOUR IN THE TREE-FROG

A.—Not a bit of it. You are right in declaring that the tree-frog, like many other reptiles and amphibia (the classical instance is that of the chameleon), has a remarkable capacity for changing its colour. In the skin of the tree-frog there are two kinds of contractile pigment-cells (chromatophores), one kind being filled with yellowish-green and the other with bluish-white pigment granules. According as the light-tinted or the dark-tinted chromatophores dilate and contract, does the colour of the animal change from light-green to a dark bluish-green. It was formerly assumed, as you assumed just now, that the frog, influenced by visual impressions, deliberately changes its colour, adapting a protective tint harmonising with that of its environment. In reality, the change of colour is purely reflex, the outcome of tactile stimuli, of which the animal is presumably unconscious in the higher centres of the brain. If you place a tree-frog upon a smooth surface, be it light-tinted or dark, grey or yellow, it always, as Biedermann showed by experiment, takes on a greenish colour, whereas upon a rough surface it becomes dark in tint. If, then, the frog does in general harmonise in colour with its environment, this is due to the fact that in nature many leaves have a smooth surface, whereas the surface of the soil is rough. There is no question of any conscious or deliberate adaptation. Nevertheless, even though utility, and therefore the selective value, of colour adaptations and mimicry has been greatly over-estimated, the organic world is full of useful adaptations whose origination may have been largely due to natural selection. I will give you a few especially characteristic examples. Before the war, we used sometimes to read in the newspapers that a recruit had mutilated himself in order to escape military service. Many animals, in like manner, mutilate themselves (autotomy) to escape their enemies. Part of the body is sacrificed in order to save the life. (See Fig. 79.)

OVER-ESTIMATE OF THE VALUE OF SELECTION

SELF-MUTILATION

B.—I suppose you are referring to the way in which a lizard's tail breaks off? I have often been astonished at the easy way in which the powerful tail is severed from the body. A few violent twisting movements are made by the creature whose tail one has seized, and instead of a lizard, one has only a twitching tail in one's hand.

A.—Where do you suppose the severance takes place?

B.—Presumably between two of the vertebræ, at the point of least resistance.

A.—A natural supposition. In reality, however, the severance occurs in the middle of one of the caudal vertebræ. From the seventh caudal vertebra to the extremity of the tail, the vertebræ are considerably elongated, and thin off at the middle like an hour-glass. At the thinnest part there is also an unossified partition-wall, and it is here that the rupture occurs. The severance is a purely reflex act, by which I mean that it occurs involuntarily, without participation of the brain. A lizard whose brain has been destroyed will, when its tail is stimulated, shed the organ as readily as will an intact animal. The reflex centre lies in the lumbar region of the spinal cord between the two hind-legs.

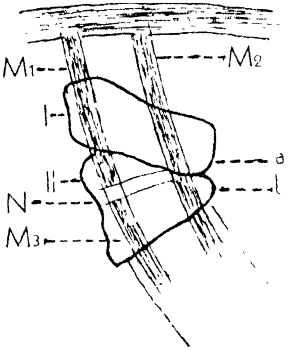

Fig. 79.—Self-amputation of a Crab's Limb.

M1, M2, M3, muscles; *b*, tuberosity of the second segment of the limb, pressed against the tuberosity, *a*, of the first segment by contracture of the muscles, whereupon the joint, N, is severed.

B.—It is astonishing that the lizard does not bleed to death.

A.—A special adaptation guards against this. Immediately after the self-mutilation, the muscles of the stump contract so firmly that severe hæmorrhage is prevented. Within a few days, the wound will have cicatrised. A new end begins to sprout to the tail, and in a few months the damage has been made good. Crustaceans and other articulata readily sacrifice their legs and their claws, which are then reproduced like the lizard's tail. Autotomy assumes interesting forms in many insects. Thus, among the termites and the ants,

Casting of the Wings after the Nuptial Flight

after the nuptial flight the queen rids herself of the wings which thenceforward would be functionless. She does so by breaking them off at the root. The loss of the wings is advantageous. The fertilised queen-ant, which is to found a new State, begins by digging herself a little burrow, in which she has to spend weeks while awaiting the ripening of her eggs. During this period of famine, she consumes

Wing-Muscles as Nutritive Material

the material contained in the powerful but now superfluous muscles of the wings, and this suffices her for the growth of the eggs. Here,

Thriftless Expenditure of the Germs of Life

once more, however, you can see how extravagant is the expenditure of the germs of life. By the time that the first larvæ have hatched out, the wing-muscle material has usually been exhausted, and thereafter the mother calmly feeds the young larvæ upon the remaining

AUTOPHAGY

B.—I have watched a peculiar action performed by leaf grasshoppers. As soon as one catches hold of the creature by the leg, it seizes this captured limb between its powerful maxillary palps and bites the member off. So common is this self-mutilation among them, that we rarely find an uninjured specimen. What is the advantage ?

BLOOD-SPURTERS

A.—If this means of defence enables a grasshopper to escape a human being, one may suppose that it also enables the creature, often enough, to escape the animals that prey upon it. It sacrifices a limb to save a life. In grasshoppers, and also in certain beetles, there is another form of self-mutilation, for they spurt a thin stream of blood at an approaching enemy.

B.—How is that possible ?

A.—By a forcible contraction of the abdominal muscles, the blood pressure is so greatly increased that the skin is ruptured in certain thin places. A master in this art is one of the Algerian grasshoppers, eugaster, which can shoot its precious blood at an enemy from a distance of as much as 18 inches. Since the blood contains acridly smelling and pungent substances, the enemy usually withdraws. When I remind you how many worms react to stimuli by breaking into pieces, each piece being able to grow into a complete animal ; how starfish cut off their rays ; and how sea-cucumbers, when touched, will often exgurgitate a large part of their viscera and leave these as prey to the enemy, without perishing in consequence—you will hardly be able to doubt the biological importance of these adaptations. We have already discussed how the Darwinian principle of selection explains the origin of such useful adaptations and the development of new species. To-morrow we shall consider how far this theory suffices to account for the development of the organic world, or whether we must look for supplementary factors of organic evolution.

movements are made by the creature whose tail one has seized, and instead of a lizard, one has only a twitching tail in one's hand.

A.—Where do you suppose the severance takes place?

B.—Presumably between two of the vertebræ, at the point of least resistance.

A.—A natural supposition. In reality, however, the severance occurs in the middle of one of the caudal vertebræ. From the seventh caudal vertebra to the extremity of the tail, the vertebræ are considerably elongated, and thin off at the middle like an hour-glass. At the thinnest part there is also an unossified partition-wall, and it is here that the rupture occurs. The severance is a purely reflex act, by which I mean that it occurs involuntarily, without participation of the brain. A lizard whose brain has been destroyed will, when its tail is stimulated, shed the organ as readily as will an intact animal. The reflex centre lies in the lumbar region of the spinal cord between the two hind-legs.

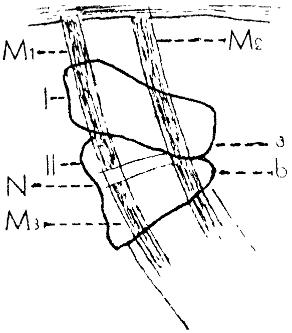

FIG. 79.—SELF-AMPUTATION OF A CRAB'S LIMB.

M1, M2, M3, muscles; *b*, tuberosity of the second segment of the limb, pressed against the tuberosity, *a*, of the first segment by contracture of the muscles, whereupon the joint, N, is severed.

B.—It is astonishing that the lizard does not bleed to death.

A.—A special adaptation guards against this. Immediately after the self-mutilation, the muscles of the stump contract so firmly that severe hæmorrhage is prevented. Within a few days, the wound will have cicatrised. A new end begins to sprout to the tail, and in a few months the damage has been made good. Crustaceans and other articulata readily sacrifice their legs and their claws, which are then reproduced like the lizard's tail. Autotomy assumes interesting forms in many insects. Thus, among the termites and the ants,

CASTING OF THE WINGS AFTER THE NUPTIAL FLIGHT

after the nuptial flight the queen rids herself of the wings which thenceforward would be functionless. She does so by breaking them off at the root. The loss of the wings is advantageous. The fertilised queen-ant, which is to found a new State, begins by digging herself a little burrow, in which she has to spend weeks while awaiting the ripening of her eggs. During this period of famine, she consumes

WING-MUSCLES AS NUTRITIVE MATERIAL

the material contained in the powerful but now superfluous muscles of the wings, and this suffices her for the growth of the eggs. Here,

THRIFTLESS EXPENDITURE OF THE GERMS OF LIFE

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to promote the persistence of pre-existent characters. He writes: "Modifications do not appear in the greatest numbers where the struggle for existence is keener, that is to say where the conditions of existence are most unfavourable, but where the struggle is least intense." Although natural selection has the advantage over artificial

SUPERIORITY OF ARTIFICIAL SELECTION

selection in that it can simultaneously get to work upon various characters at once, in other respects it is inferior to artificial selection. If, in a huge herd of domesticated cattle, only two individuals exhibit a modification useful to man, the breeder can pick out these two animals from among thousands and use them only for breeding purposes. On the other hand, let us suppose that among all the hares in a specified area, two, thanks to their colour, are better adapted to the environment than all the rest, does it seem probable that these two, because of so slight an advantage, will escape their enemies when all the rest succumb? Even if these two were, by a lucky chance, to escape destruction (when, obviously, a good many others would escape as well) is it probable that the two animals which alone have a useful variation will meet and pair? They would be much more likely to pair with animals that did not exhibit the variation in question. In that case, however, the useful character would be watered down and would disappear after a few generations. Therefore, as useful

BEGINNINGS OF USEFUL STRUCTURES HAVE NO SELECTIVE VALUE

variations appear only in isolation, they have no selective value. Above all, we find it difficult to explain how selection can get to work upon the initial stages of useful structures. Agreed, the remarkable

CALLIMA (THE LEAF-BUTTERFLY)

resemblance a callima has to a leaf, may enable the animal to elude the eyes of a devourer. But, according to the theory of natural selection, callima must have developed to its present state by the gradual intensification of trifling modifications in ancestral butterflies which did not resemble leaves. How could natural selection bring that about? The first modifications in colour and markings did not make the butterfly resemble a leaf, and therefore could not have given it any advantage over its unmodified congeners, or at any rate an advantage having selective value. Not until a high degree of resemblance to a leaf had been achieved, could natural selection get to work and increase the resemblance.

B.—Yes, I see that is so. Natural selection would have no lever to work with until the new character had already attained a fair degree of perfectionment. I also perceive that modifications occurring only here and there would tend soon to disappear, being watered down by crossing with unmodified types.

THEORY OF MIGRATION

A.—Wagner, in his theory of the origin of species through geographical isolation (the theory of migration), has endeavoured to cope with this difficulty. If modifications occurring here and there are not to be neutralised by repeated crossings with the prevailing type, it is necessary that, as occurs in the course of artificial selection, the modified animals shall be set apart from animals of the customary type. If, by active migration or by a biological catastrophe, some of the members of a species were transferred to new conditions, and these happened to be members displaying a useful variation, that might prove the origin of a new type. In the beginning of the fifteenth century, certain Portuguese mariners landed rabbits on the little island of Porto Santo near Madeira. Within the subsequent five centuries, these rabbits have developed into a new variety, so different that we may almost speak of it as a new species. Porto Santo rabbits are smaller and less timid than our rabbits ; they have a reddish fur ; and they do not pair with their European progenitors. Of course it cannot be taken for granted that selection has produced these changes. The transformations that have occurred may have been brought about by the transforming influence of the new environmental conditions.

The Rabbits of Porto Santo

Tendentious Variability

B.—May we not suppose that changed environmental conditions, acting in like manner upon numerous individuals of a species, may simultaneously evoke in them useful modifications of the same kind ? As soon as a great number of identical variations have arisen, selection would certainly be able to favour quicker transformation in the direction of the useful variations.

A.—In my opinion, only upon such a supposition is it comprehensible that natural selection can have developed the numberless adaptations and new qualities that have arisen. But if we take such a standpoint, the chance to which natural selection appeals is largely deprived of its importance, and the greater part of the formative energy is referred to the organisn. This implies an admission that a living creature (for unknown reasons) reacts purposively to environmental influences, or as Pauly, and before him Lamarck, expressed it, that an awakening need brings with it the means for its own satisfaction. In that case selection would only be an accessory factor in the origin of species.

Revival of the Notion of Vital Force

B.—That implies a revival of the old mystical idea of vital force.

A.—By no means. Such an assumption is less mystical than when we ascribe all purposive modifications to the blind working of chance. The postulation of internal voluntary factors would only be mystical if we regarded such initial forces as fundamentally inexplicable, and as operative outside the domain of natural law. In some measure, as Pauly remarks, the theory of natural selection puts the cart before the horse, inasmuch as it makes reproduction the

Pauly

effective cause, the origin, of purposive adaptations, although the organism has to be purposively adapted to the conditions of existence before it can survive to reproduce its kind. We have experimental proof that environmental influences can exert a formative and modificatory effect. We have also learned that, so long as the environmental conditions remain unchanged, species, likewise, can remain unchanged throughout the æons. We saw this most plainly in the case of the

HAIR-STARS OF THE DEEP SEA

hair-stars of the Cambrian ; and to-day there still dwell, in the deep sea, hair-stars which are extraordinarily like those of that remote epoch.

B.—The strangely modified types found as endemic species on little islands far from the mainland, also speak for the formative influence of environment.

ELECTRIC ORGANS

A.—I am not yet at an end of my objections. How can natural selection explain the origin of such highly differentiated a structure as the electric organ in the tail of the torpedo or electric ray—an organ which has been produced by modification of cross-striated muscular tissue ? Even in its present degree of perfectionment, this structure is of no discernible use to its possessor. The current developed by the electric organ of the ray is so weak that its presence can only be detected by delicate apparatus. Consequently, we cannot suppose it to be a valuable defensive weapon, like the electric organ of the electric eel (Gymnotus electricus). One would have been inclined to suppose it to be vestigial, did not the history of its evolution contradict any such theory.

B.—If the foregoing considerations are sound, one can only suppose natural selection to be effective on the proviso that there exists a definite tendency to evolve in a particular direction. Untendentious variability would be of no use, since a selective value is only achieved when there is an accumulation of slight variations in a particular direction. Besides, the record of the rocks confirms the notion that there have been a number of such persistent voluntary trends.

NAEGELI'S IDEA OF A PERFECTIVE IMPULSE

A.—Such a view has long been advocated by numerous investigators, and has of late gained new adherents. Still, that does not mean that we must appeal to supernatural energies, to a " perfective impulse " in Naegeli's sense. Eimer considers that the cause of tendentious evolution must be sought in environmental factors, in the effects of climate and nutriment on living beings. Regardless of utility or detriment, evolution marches along its course, and, according to Eimer, the only work of selection is to preserve useful variations and eliminate harmful ones. You did well to mention the record

PERSISTENCE OF EVOLUTIONARY TRENDS

of the rocks, where we find numerous instances of the way in which an evolutionary trend, once begun, is persisted in, sometimes transcending the limits of utility, and leading to the extinction of the organism concerned. Even among contemporary fauna, we find many instances of such an exaggerated evolution. One of the most striking examples

THE HORNED HOG (BABIROUSSA)

is that of the tusks of the horned hog (babiroussa) in Celebes, which have grown so long as to reach the animal's forehead, and have lost their utility whether as weapons or as instruments for rooting in the soil. The theory of natural selection is unable to account for the

ATROPHY OF VESTIGIAL ORGANS

origin of such structures. The complete atrophy of certain vestigial organs, too, can scarcely be explained by natural selection. Thus

WHALES

in certain whales, we find, as ultimate vestiges of the atrophied hind limbs, imbedded in the muscular masses of the hinder part of the body and not connected with the spine, a hip bone, and in others a thigh bone, so tiny that they scarcely comprise a millionth of the body weight. The atrophy of a whale's hind limbs when they cease to have any useful function can be explained by selection, since as persistent but useless vestiges they deprive the body of nutriment which can be better used for other purposes ; but whether these vestiges are a trifle larger or a trifle smaller can scarcely be of importance, of advantage or disadvantage, to leviathan. When such

LIMITED POWER OF SELECTION

vestiges have already become very small, selection must surely have ceased to operate upon them, and we cannot see how it could lead to complete atrophy. But one of the most important objections to the view that selection is omnipotent remains to be considered. It is certain that variability must be one of the basic requirements for the efficacy of selection. A second question which arises is whether selection, working upon variations, can really produce new species with entirely new characters, or whether natural hindrances would not soon counteract selection.

B.—Surely this question has been plainly answered in the affirmative by the success of artificial selection ?

A.—On the contrary, the achievements of artificial selection are, by certain investigators, regarded as the most striking proof of the inefficacy of natural selection in the Darwinian sense. According to Wolf, the facts supply, rather, empirical proof of the fixity of species, inasmuch as, by selective breeding, we can only modify the type of our domestic animals within fixed limits. " The restrictions imposed upon the workings of artificial selection ", writes Wolf, " run counter to the first suppositions of the theory of natural selection, which is forced to presuppose living matter to be so plastic that it can be modified to any extent and in all conceivable directions. . . . There is no evidence of any such unlimited plasticity."

B.—How can Wolf justify so blank a denial ? It seems to me that many of the facts you have recounted to me give him the lie.

A.—I, too, think Wolf's attitude of denial over-emphatic. Certainly, many of the achievements of artificial selection, such as the production of widely diversified races of pigeon, do give us the impression that the organism can be kneaded like dough, so that selection can give it any form we please. Still, a critical consideration of the facts does indeed disclose limits which even the most careful selection

THE SUGAR-BEET

does not enable us to overstep. When, in the middle of the nineteenth century, in Germany, the systematic culture of the sugar-beet began, the sugar-content of the ordinary beetroot (Beta vulgaris) out of which the sugar-beet was bred, ranged from 7 to 8%. In the course of a number of years it was possible to increase the sugar content of the selected plants to 16%. No increase beyond that percentage has been possible.

B.—Upon what does the failure to produce better results depend, when, at first sight, it seemed as if a much greater increase would be possible ?

QUETELET'S LAW

A.—If you examine a large and indiscriminate assortment of peas or beans as to their size, you will discover a remarkable law. All the variations, in any kind you study, are on either side of a mean. Most numerous are peas and beans of the average size, while the deviations from the mean become less numerous the more they tend towards the extremes of " very large ", on the one hand, or " very small ", on the other. This law, which is known as Quetelet's law, applies, not only to differences in size, but, it would appear, to all possible variations. (See Fig. 80.) Now, in the present connexion, the important question is what significance these slight serial, fluctuating, individual variations have as regards the formation of species. In Darwin's view, it would always be possible for persistent selection

SHIFTING OF THE MEAN VALUE

of the extreme forms to shift the mean value, and by degrees to intensify the particular character upon which the breeder is working. What do we actually find ? Suppose that in three separate beds we cultivate three different races of bean, one of them small beans ranging from 6 to 14 mm. in length ; the second, beans of medium size, ranging from 11 to 19 mm. ; and the third, large beans, ranging from 16 to 24 mm. in length. Although the beans of these three races vary in size, and the largest beans of the medium race are longer than the smallest beans of the largest race—provided the cultural conditions remain constant, the average length remains the same in each race. In the case of the smallest race, it ranges about the mean 10 ; in the middle-sized race, about the mean 15 ; and in the largest race, about the mean 20 mm. From the size of an individual bean, therefore, you cannot tell to which of the three races the specimen belongs. A bean 16 mm. in length may be an average specimen of the middle-sized race, a large specimen of the small race, or a small specimen of the large race.

B.—What has this to do with the problem of natural selection?

A.—First of all it shows you that two individuals of different races may be outwardly similar, although their hereditary equipment differs. In other words, the apparent type (phenotype) and the hereditary type (genotype) are not identical.

PHENOTYPE AND GENOTYPE

B.—How can you discover to which of the two races the bean in question belongs?

A.—Only by breeding from it. If I plant my bean which is 16 mm. in length, and if, after self-fertilisation, in the youngest generation I get beans ranging from 16 to 24 mm. in length, then I know that my bean belonged to the big race. Assuming that the beans with which we are dealing belong, so far as their hereditary features are concerned, to pure races, they will, when bred from generation to generation under like conditions, always produce beans showing the same average size and the same range of variation. The result will be identical whether, for further breeding, I select from among these specimens of the large race the smallest or the largest individuals.

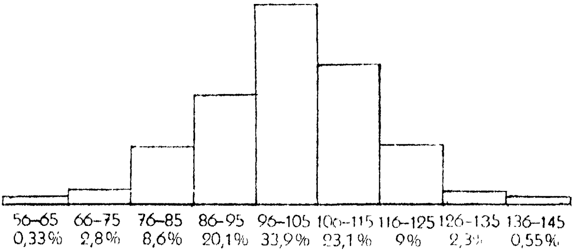

FIG. 80.—THE DISTRIBUTION OF INTELLIGENCE. (After LEWIS M. TERMAN.)

The diagram shows the distribution of intelligence (as demonstrated by intelligence-tests) in 905 children of ages varying from 5 to 14, taken at random. The most numerous are those of average intelligence from 96 to 105, whilst the number of those with high intelligence (106-145) and those with low intelligence (95–56) gradually falls off on either side. The curve that might be drawn touching the tops of the columns is the curve of probability.

INHERITANCE OF RACIAL CHARACTERS

B.—May I draw an inference, in order to see whether I have understood you? What you imply is that the bean transmits by inheritance, not its individual character of being 16 or 24 mm. in length, but the racial character, of having an average length of 20 mm.?

A.—Excellent! Now let us try another experiment. We will take beans from the middle-sized race, having an average length of 15 mm. We will plant some of these in well manured garden soil, and the remainder in sandy ground. We will carefully water the fertile and sunny bed where the former are planted, whereas the sandy ground shall be unduly shaded, and neglected. As a result, from the fertile bed we shall harvest beans whose average length has risen to 22 mm., while the individual specimens will vary around this mean from 18 to 26 mm. On the other hand, the beans grown under unfavourable conditions will have an average length of no more than 8 mm. In other words, by especially favourable conditions we are able to raise the average length of the middle-sized beans above the maximum length of beans of the large race, whereas, under unfavourable conditions, the average length is greatly reduced. What do you infer from the results of these experiments ?

HEREDITY FACTORS PERSIST UNCHANGED

B.—That the phenotype is the combined outcome of genotype plus environmental conditions.

A.—Right. Still, despite this shifting of the mean, the heredity factors remain unaltered. As soon as we transplant the large beans of the middle-sized race to the original conditions, the average length of the crop falls back to 15 mm.

B.—But what will happen if I take the largest beans of the middle-sized race, and continue to breed from them under exceptionally favourable conditions ? Shall I not then be able to increase the average length ?

A.—No, you are completely mistaken. The favourable conditions have had their full possible effect. The offspring of these largest beans of the middle-sized race, will continue to oscillate in length round a mean of 22 mm., ranging from 18 to 26 mm. You may go on selecting and breeding under favourable conditions as long as you please, and you will not shift the mean any farther. It is plain from this that the favourable effect of improved environmental conditions is produced only upon individuals, whilst the heredity factors remain unmodified. If you restore the larger beans you have secured to the original conditions of their progenitors, they will relapse to the size of their parents. As far as our experience goes, favourable conditions, no matter how long they remain in operation, cannot in this way produce any new heritable racial characteristics.

B.—But surely your statement conflicts with all the results achieved by breeders ? Every pigeon-fancier would laugh you to scorn if you were to tell him that artificial selection had no effect.

PURE LINES

A.—I will solve the enigma for you, and explain the apparent contradiction. In our experiments with beans, we were dealing with pure races, that is to say with plants with hereditarily stable (homozygotic) germ-cells ; and we bred strictly in-and-in. The beans were always fertilised with their own pollen. The animal breeder, on the

RACIAL MIXTURE (MISCEGENATION)

other hand, works upon impure races, upon persistent hybrid stocks. If we were to take a number of small specimens of the large race of beans, ranging from 16 to 19 mm. in length, and to shake them up in a bag with the longest beans of the middle-sized race, whose largest specimens may attain a length of 19 mm., no one could tell from a glance at these beans that they composed a racial mixture. Only breeding from the mixed specimens would clear up the matter. If, out of our bag, we were always to pick for breeding the largest specimens, then we should find, in some of the offspring, beans having an average length ranging from 15 to 20 mm. We should gather the impression that our selection had modified, not only the phenotype, but also the genotype. All that we should really have effected would be that, out of a racial mixture of " middle-sized " and " large " beans, we had by selection bred the large race pure once more. But as soon as that has been effected, as soon as we are working once more with a pure line, any further selection will be fruitless. Thus by artificial selection we can only breed out qualities that were already present in the hereditary equipment of the parents used for the breeding experiment. Selection cannot create new heredity factors. New characters can only be created by combining diversified heredity factors or genes in father and in mother.

B.—On the whole I understand your exposition, but the processes that go on in the germ-cells, the processes upon which the foregoing results depend, remain obscure to me.

Selective Breeding cannot Create new Heredity Factors

A.—You will learn more about that to-morrow. Enough for the present that you should realise how individual, fluctuating modifications are not transmissible by inheritance, so that natural selection cannot account for the formation of new species. Natural selection, working upon fluctuating variations, cannot account adequately for the origin of species in the organic world. Selective breeding cannot create new heredity factors.

Fluctuating Modifications not Transmitted by Inheritance

B.—If individual variations are not inherited, then it seems to me that natural selection cannot bring about any serious transformation.

A.—Side by side with the non-heritable fluctuating variations, there also occur heritable modifications. Darwin knew of this distinction, but did not lay much stress on it. It is, however, these heritable modifications which alone provide the material upon which natural selection can work for the production of new species. I shall defer the consideration of this matter until you have become acquainted with the laws of heredity.

Elimination of the Less Fit by the Struggle for Existence

B.—I suppose, then, that the most important rule of the struggle for existence is that, with fair certainty, it eliminates all low-grade individuals, so that they cannot transmit their morbid trends, and thus the species is kept healthy and vigorous.

Weakly Individuals are Killed

A.—Yes, you are right, and the recognition of the fact is of the utmost importance to the destiny of civilised man, in whom the struggle for existence has to a large extent been abolished, whilst, by medical aid and various social provisions, the less fitted are to a great extent preserved from destruction. This, too, is a matter which will have to be discussed in detail by and by. Of course under natural conditions, crippled specimens may live for years and may reproduce their kind. For instance, Hofer caught a carp two years old, to find that the creature's mouth had never been properly formed, and that it could only take nutriment through the gill-slits. Nevertheless, it had not been eliminated by the struggle for existence, and was only caught haphazard. Still, in general, under natural conditions, selection sees to it that only valid specimens survive and reproduce their kind. Many animals that lead a social existence destroy congenitally inadequate specimens of their kind. It is well known, for instance, that in autumn marmots and lemmings kill the weakly specimens of their race ; and in autumn many migratory birds destroy those members of the species which are not strong enough to bear the hardships of the long flight to the south. The methods which the Spartans are said to have applied drastically by exposing weakly children are obviously inapplicable among civilised races, for, as Lenz emphatically remarks, " the deliberate slaughter of incurably morbid children would be a grave disregard of that respect for individual life which is one of the fundamentals of social order ". But a civilised people has other and humaner ways of preventing a degeneration of the stock or stirp. These ways will be discussed later.

This Method cannot be Applied to Themselves by Civilised Races

Sexual Selection

B.—Did not Darwin explain the origin of sexual differences, and, above all, of ornamental secondary sexual characters, by natural selection ?

A.—You put your finger, there, upon one of the weakest points of the theory of selection. Darwin's doctrine of sexual selection accounted for the origin of special weapons among the males of various species on the ground that (as is a fact) stags, bulls, etc., during the rutting season, fight fiercely for the possession of the females. He held that, in general, the best armed males had the greatest chance of reproducing their kind, whereas the weaklings were forced to remain bachelors. But every man well acquainted with the life of the wild, every competent sportsman and every forester, will protest against such a contention, and will tell you that while rutting stags, for instance, with fine branching antlers, are engaged in a life-or-death struggle, the younger and weaker stags, whose antlers are as yet little developed, seize the opportunity of gratifying their sexual desires. As to sexual ornaments, we are at a loss to account for them. They give their possessors no advantage, and indeed the most strikingly coloured males cannot but find them a drawback in the struggle for existence. In such cases, say the champions of sexual selection, an intelligent breeder, namely the female, sets selection to work, bestowing her favours upon the best adorned males. Inasmuch as in many fishes, amphibia, reptiles, etc., the wedding dress is only assumed in the pairing season, the idea does not seem prima facie absurd. Many birds, such as blackcock, mountain-cock, buzzards, pheasants, etc., dance before the females in the breeding season, making the utmost possible display of their peculiar beauties. But if you have seen much of blackcock or of mountain-cock, you cannot have failed to notice how little attention the hen birds pay to the prancing of the cocks, and how, often enough, the shabbiest-looking among the cocks make the greatest number of conquests. One would certainly be overrating the æsthetic taste of the lower animals if one were to suppose that their critical choice had brought about the origination of such works of art as the wonderful tints and the symmetrical markings on the wings of a butterfly or the tail of a peacock. Besides, it is most improbable that our own sense of beauty coincides with that of the lower animals. Steche gives a more plausible explanation for the origin of these sexual adornments. Throughout nature, the male shows himself to be the more progressive partner, the one most ready to make innovations, whereas the female is comparatively conservative. He adduces in proof that in youth the males are as soberly attired as are the females throughout life. The specific male characters do not appear until sexual maturity approaches. In like manner, among many butterflies, the females are less differentiated, their colouration and markings showing more plainly than do those of the males the characteristics of the parental stock. The males are far more widely divergent from that type. Maybe the greater variability of the males, and the richness of their colouring, are, in part at least, dependent upon metabolic processes. In the production of the eggs, which are so richly supplied with yolk, a great call is made upon the resources of the hen-bird's store of nutriment, and we may well suppose that the cock devotes his superfluity in this respect to ornamental purposes. We must not, therefore, be too ready to reject Steche's assumption that selection has produced not the brilliant colouring of the male, but the dinginess of the female, which has to care for the brood, and needs protective colouration that will prolong her life, whereas the role of the male is mainly played out when he has fecundated the female. Such an assumption is supported by the fact that in bush-quails (turnices) and in phalaropus, the females are larger and more prettily tinted than the males, dance before the males, and even fight for their possession, whereas in the aforesaid species the inconspicuously coloured males sit upon the eggs. But these are mere hypotheses, which may be sound or unsound. We had better admit frankly that we are not as yet in a position to give any satisfactory explanation of the origin of sexual adornments.

THE MALE IS THE MORE PROGRESSIVE PARTNER

B.—There are a good many more questions I should like to ask you, but I am tired, and my attention wanders, so we had better stop for to-night.

A.—All right. We will postpone until the morrow our consideration of the laws of heredity, and will deal with other theories of evolution on the last days of our vacation.

NINETEENTH EVENING

LAWS OF HEREDITY

Carriers of the Heredity Factors

A.—To-day I am going to tell you about the wonderful mechanism thanks to which the fertilised ovum of the sea-urchin or of a human being invariably produces, in the respective cases, a sea-urchin or a human infant, equipped with the qualities or characters of both parents ; combining, indeed, to some extent the characters or qualities of grandparents and earlier ancestors in a strange admixture—to transmit this heritage faithfully to subsequent generations. On the thirteenth evening, when giving you an account of the process of cell-division, I told you what reasons we have for believing the chromosomes to be the carriers of the hereditary equipment. Perhaps you will be good enough to summarise what I told you then. (See Fig. 81.)

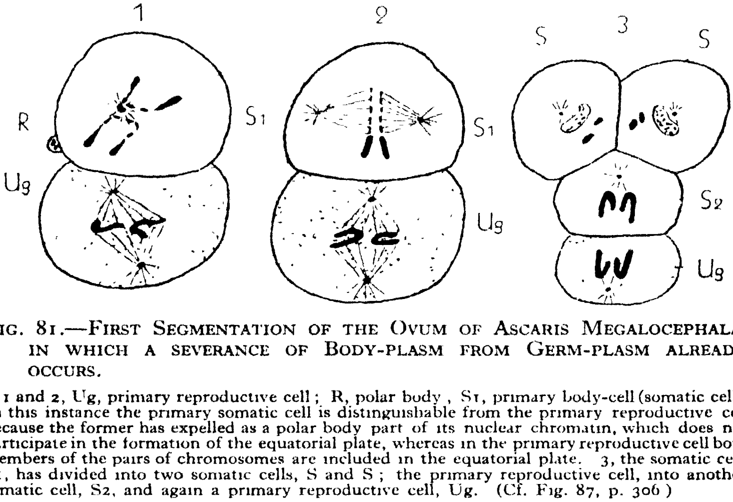

Fig. 81.—First Segmentation of the Ovum of Ascaris Megalocephala, in which a Severance of Body-plasm from Germ-plasm already occurs.

1 and 2, Ug, primary reproductive cell ; R, polar body , S1, primary body-cell (somatic cell). In this instance the primary somatic cell is distinguishable from the primary reproductive cell because the former has expelled as a polar body part of its nuclear chromatin, which does not participate in the formation of the equatorial plate, whereas in the primary reproductive cell both members of the pairs of chromosomes are included in the equatorial plate. 3, the somatic cell, S1, has divided into two somatic cells, S and S ; the primary reproductive cell, into another somatic cell, S2, and again a primary reproductive cell, Ug. (Cf. Fig. 87, p. 306)

Body-Cells and Germ-Cells

B.—The body-cells of every species of animal or plant contain, for each species, a constant number of chromosomes, which is always an even number. Taking man, for instance, we find in all his body-cells 48 chromosomes; and only in the mature reproductive cells is the number of the chromosomes reduced to half of that, namely 24.

Reduction-Division

Independent Assortment of Paternal and Maternal Heredity Factors

Significance of Fertilisation

This reduction by one half occurs during the ripening of the reproductive cells, when, in what is called the reduction-division of the ovocytes and the spermatocytes, the longitudinal splitting of the chromosomes ordinarily characteristic of cell-division fails to occur, and half of the undivided chromosomes are allotted to each of the two daughter-cells. In every body-cell, and also in the ovocytes and the spermatocytes, all the chromosomes are present in pairs, one member of each pair deriving from the father and the other member from the mother. In the reduction-division, the pairs of chromosomes are separated once more, so that the young spermatozoa and ova receive from each pair of chromosomes only the paternal or only the maternal element. To give you an instance, and putting the matter somewhat crudely, during this division the paternal chromosome which contains the gene for blue eyes of the blue-eyed father will be allotted to the young reproductive cell A, whilst the chromosome containing the gene for brown eyes from the brown-eyed mother will be allotted to the young reproductive cell B. Both ova and spermatozoa, therefore, contain, for each heritable rudiment, either a paternal or a maternal gene, which form a motley mixture. In the act of fertilisation, the spermatozoon conveys the hereditary equipment deriving from both its parents into the ovum, so that the fertilised ovum once more contains the full number of chromosomes characteristic of the species in question, each of these chromosomes being supplied with two genes, one from the male parent and one from the female parent, for each heritable character. According as, during the development of the embryo, the paternal or the maternal genes come into their own, does the child have a greater resemblance to the father or to the mother.

A.—Since you have so good a grasp of the matter, we can go straight to the heart of things, and inquire whether the experience of practical breeders is in conformity with the data of cytology. In order to investigate the more intimate processes of heredity, we must avoid choosing two individuals resembling one another very closely, for if we did so we should learn nothing more than what daily experience has long since taught us, namely that the ovule and pollen of a lily always produce a lily and that the ovum and spermatozoon of a human being always produce a human being. What we are now interested in is to ascertain how the particular divergent genes of the parents behave, and in what way, in what kind of admixture, they manifest themselves in the phenotype of the offspring. We will therefore choose for our breeding experiments individuals differing from one another in one or in several typical characters.

The Work of Gregor Mendel

B.—As far as I know such breeding experiments were first made by the Augustinian monk Pater Gregor Mendel, about the year 1866.

Mirabilis Jalapa (Four-o'-Clock)

Pairs of Characters

A.—Yes, that is so. But the scientific world of those days was extremely sceptical as regards Mendel's shrewd inferences and contentions. Very little was then known about the minuter processes of cell-life. Consequently Mendel's work lapsed speedily into oblivion. Not until more than a third of a century later, that is to say in the early years of the twentieth century, was their importance independently and almost simultaneously recognised by de Vries, Correns, and Tschermak. What, then, was Gregor Mendel's epoch-making discovery ? One of the favourite ornaments of our flower-beds is Mirabilis jalapa, or four-o'-clock, a plant of Mexican origin. Let us make our first experiments with this. We choose a red-flowering and a white-flowering plant, whose purity has been ascertained by breeding them true for several generations ; and we concentrate our attention upon the character red-flowering and white-flowering. We leave out of consideration whether the parent plants differed in other characters than these. The colour of the flowers, red and white respectively, form a pair of characters. What do you think, if we cross a red-flowering four-o'-clock with a white-flowering one, will be the colour of the flowers of the offspring ? (See Fig. 82.)

B.—I suppose such a crossing will produce plants having pink flowers, the characters of the respective parents being mingled.

Mixed Types

The Second Hybrid Generation

A.—Right. It is, moreover, a matter of indifference whether the red-flowering and white-flowering parents are father and mother or mother and father respectively. Suppose that I now, taking these pink-flowering hybrids of the first generation (the so-called first filial generation, written for short F_1), fertilise them with their own pollen, breeding strictly in and in, what will be the colour of the flowers in the second hybrid generation, or the second filial generation (F_2) ?

B.—Of course we shall once more get nothing but pink-flowering plants, since the parents were both pink-flowering.

A.—No, you are wrong this time. Here you will find another proof that phenotype and genotype are two very different things. It is true that the majority of the plants of the second hybrid generation are pink-flowering ; but side by side with these you will have plants with red flowers and others with white flowers.[*] Thus some of the offspring have reverted to the type of the respective grandparents (that of the paternal generation, called for short P). In other words, there has been a segregation of the grand-parental qualities which were mingled in the first hybrid generation. Now, the most

FIXED RATIOS

remarkable feature of the situation is the fixed ratio among the pink-flowering, the white-flowering, and the red-flowering plants in the second hybrid generation. You may repeat the experiment as often as you please, and you will always find 50% specimens of the pink-flowering mixed type, 25% white-flowering plants, and 25% red-flowering plants. You will have a still greater surprise if you go on breeding from the individual plants of this second hybrid generation, with the proviso that you always cross pink-flowering plants with pink-flowering, red-flowering with red-flowering, and white-flowering with white-flowering. For you will find that the red-flowering and the white-flowering four-o'-clocks of the second hybrid generation breed true, producing in each case only red-flowering or white-flowering plants. The pink-flowering plants, on the other hand, when self-

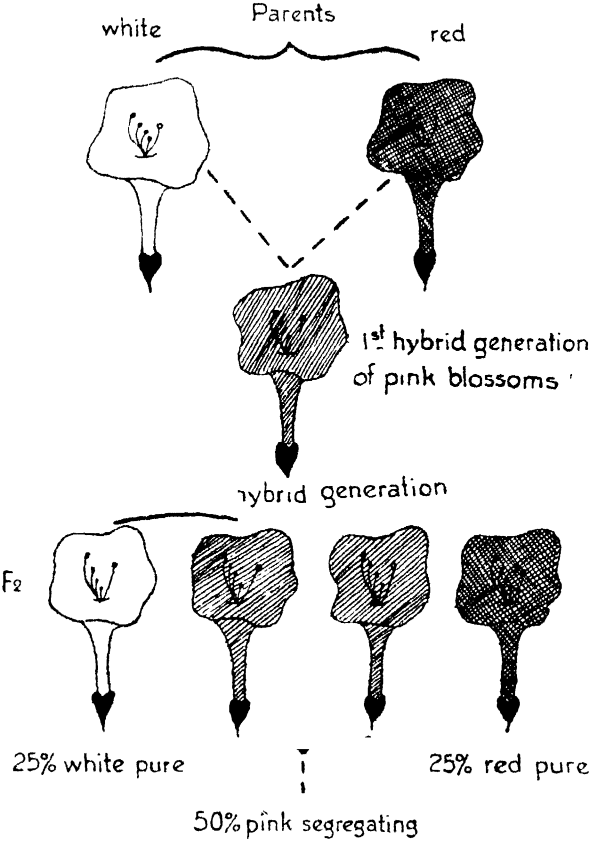

FIG. 82.—CROSSING OF A RED-FLOWERING WITH A WHITE-FLOWERING FOUR-O'-CLOCK.

fertilised, segregate in the subsequent and in all following generations in the same numerical proportions of 50% pink-flowering, 25% white-flowering, and 25% red-flowering plants.

B.—Upon what does this segregation among the offspring of the pink-flowering plants depend, and why do the white-flowering and red-flowering plants breed true?

A.—Although Mendel did not know what is now known to us about the intimate processes of cell-division, he maintained that to "red-flowering" or "white-flowering" germs correspond in the germ-cells of the parental plants a heredity factor producing red flowers or white as the case might be. In the act of hybridisation, these two heredity factors were contributed to the fertilised ovule, coupling to form a paired rudiment red-white. All the developing plants of the first filial generation contained two colour rudiments, the carrier of the tendency to produce red flowers and the carrier of the tendency to produce white flowers. Since, in the case of development, each of these heredity factors exerted an equal influence, the result was the production of a mixed type, with pink flowers.

B.—But how does it happen that the offspring of these pink-flowering hybrids segregate in so remarkable a fashion, and always in fixed ratios?

Mendel's Interpretation

A.—The solution of this enigma, which Mendel achieved without having any knowledge of the processes of cell-division, is one which you ought to be able to discover for yourself. As you know, during the reduction-division of the reproductive cells, the maternal and paternal heredity factors separate. In the young ovules or pollen-grains of the pink hybrids there is always but one colour-producing heredity factor (gene), a red one or a white one as the case may be. In other words, in respect of the character flower-colour, the hybrids produce pure (homozygotic) germinal cells, this meaning that the hybrid produces two sorts of ovules, 50% of them containing the gene red and 50% of them the gene white; and also two kinds of pollen-grains, of which, in like manner, 50% contain the gene red and 50% the gene white. What combinations are possible in the act of fertilisation, among these two different sorts of ovule and of pollen grain, if I breed in-and-in from the pink hybrids, fertilising them with their own pollen?

Possible Combinations of Heredity Factors

B.—I must think that over for a moment. As far as I can see, four combinations are possible:

Red pollen grain plus red ovule will produce red flower = 25%
Red pollen grain plus white ovule will produce pink flower }
White pollen grain plus red ovule will produce pink flower } = 50%
White pollen grain plus white ovule will produce white flower = 25%

LAW OF PROBABILITY

A.—You see, then, that the pink hybrids, when self-fertilised, do not produce nothing but hybrid forms, but segregate. By a simple application of the law of probability we discover that there must be twice as many mixed forms produced as red-flowering or white-flowering offspring. Since the red-flowering or white-flowering individuals which throw back to the ancestral characteristics are generated in each case from a red pollen grain plus a red ovule, or from a white pollen grain plus a white ovule, they contain, of course, only the heredity factor red or the heredity factor white; and can therefore only procreate homozygotic reproductive cells, and must, just like their grandparents, when self-fertilised, breed true, producing only red-flowering or only white-flowering plants as the case may be.

B.—When one continues to breed from the pink hybrids, fertilising them with their own pollen, it is a matter of pure chance whether a red pollen grain encounters a red ovule or a white ovule, or whether a white pollen grain encounters a white ovule or a red ovule. I fail to understand, therefore, why, as the outcome of such chance encounters, there should be such strict numerical proportions among the offspring. Chance might just as well bring it about that all the pollen grains I use for fertilisation contain only a red gene, and light only upon red ovules. In that case all the hybrids of the second generation would be red-flowering.

A.—That might happen if you had only a very small number of offspring, three or four, for instance. But when you raise 100 or 1000 plants, pure "chance" is ruled out, and the law of probability presides over the results—perhaps the only natural law to which there are no exceptions, provided always that we deal with a sufficiently large number of instances. Take the spinning of a coin, for instance. If you spin a penny in the air, chance decides whether it will fall heads or tails. If you spin a milliard of pennies in like manner and

FIVE HUNDRED MILLION PENNIES

count the results, you will always find almost exactly 500,000,000 pennies showing heads, and 500,000,000 showing tails. (See Fig. 83.) Let us stick to our hybridisation experiments, however, and, leaving four-o'-clock for the moment, let us undertake similar investigations with a red-flowering and a white-flowering pea. Once more our pair of characters is red-white.

B.—I do not think you need to recapitulate the results of such an experiment. I have grasped the principle and can tell you the result. In the first hybrid generation you will have only pink-flowering peas; the subsequent generations will always segregate in the ratios 1 : 2 : 1.

A.—No, my friend, the ways of nature are not so simple as you suppose. To outward seeming, at any rate, the results of this experiment will be very different. All the hybrids of the first generation are red-flowering peas; they reproduce the character of only one of the two parents, and in aspect are not distinguishable from their red-flowering parent. The white-flowering tendency appears to have been completely suppressed.

B.—You make my head reel. Surely the white-flowering trend was rooted in a chromosome, and must therefore, as in the case of the four-o'-clock, encounter in the fertilised ovule a red-producing gene, and therefore engender a red-white pair of characters. A heredity factor, a gene, cannot be thus shuffled out of the world.

A.—I never said that the gene for white was shuffled out of the world, but only that it was suppressed, and that, in the first hybrid generation, it gave no sign of its existence.

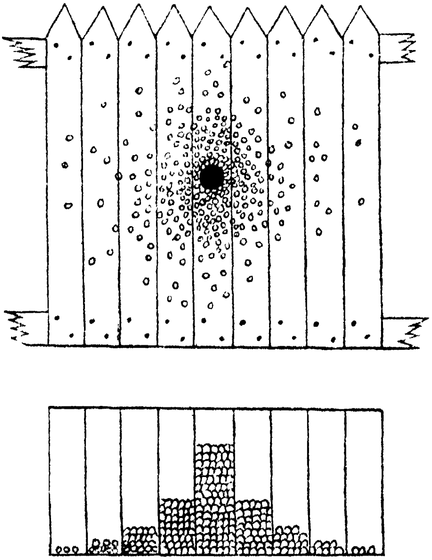

Fig. 83.—Curve of Probability. (After P. Popenoe.)

Supposing deviation in all directions to be equally probable, as in the case of the bullet-impacts when a marksman fires at a target, the hits will be distributed round the centre of the target in the manner shown in the upper part of the figure. In the lower part they are assorted in columns according to their nearness to the centre. Much the largest number of hits are in the middle compartment, and the number falls off gradually in the compartments to right and to left. A curve drawn over the tops of the columns of hits will be the normal "curve of probability." The larger the number of shots, the more regular will be the curve.

B.—My bewilderment persists.

A.—You will not be able to understand until I disclose the further course of the investigation. Let us fertilise the red-flowering hybrids of the F_1 generation with their own pollen. Now you will get a surprise. Although both the parents bore only red flowers, in the second hybrid generation (F_2) we find only 75% red-flowering specimens, for in 25% of the peas the red-flowering character which had been completely suppressed in the first hybrid generation once more becomes manifest. If we go on breeding from the white-flowering hybrids of the second generation, fertilising them with their own pollen, we find, just as we did with the white-flowering four-o'-clocks of the second filial generation, that they breed true, and continue to produce nothing but white-flowering peas. The red-flowering hybrids, on the other hand, when self-fertilised, continue in all succeeding generations to segregate once more in the ratio of 1 : 3. Always we get 75% red-flowering plants, which will segregate when bred further, and 25% white-flowering plants which breed true.

B.—The facts are amazing, but I cannot understand them. According to the law of probability there ought to have been, in this case likewise, formed 50% red and 50% white pollen grains, and also 50% red and 50% white ovules, which, when used to produce a second hybrid generation, ought to unite in accordance with the four possibilities already considered in the case of the four-o'-clock.

Dominant and Recessive Characters

A.—Well, so they do. The difference between the pea and the four-o'-clock is that in the four-o'-clock the gene red and the gene white are equally energetic, and each of them makes itself felt to the same extent in the phenotype of the offspring. That is why, when a red pollen grain fertilises a white ovule or a white pollen grain fertilises a red ovule in four-o'-clock, a pink mixed type results. In the pea, however, the white gene is, in some way or another, weaker than the red gene, and cannot assert itself as against the latter. We speak of the more powerful character, which in this case is red, as dominant, and of the suppressed white character as recessive. The ratio in which red and white genes encounter one another in the fertilised ovule is exactly the same in the pea as in the four-o'-clock; this signifying that in the pea, likewise, we have 50% of the offspring

Heterozygote and Homozygote

containing red and white genes, that is to say equipped with impure (heterozygotic) reproductive cells, and 25% with only red, and 25% with only white genes, that is to say, containing pure (homozygotic) reproductive cells. Of all the fertilised ovules, of course the 25% which contained only red genes must produce red-flowering offspring; but also the 50% of ovules in which red and white genes have come together will likewise produce red-flowering plants, since red is dominant over white in the phenotype of the offspring, the white gene being recessive and its appearance repressed. These plants are, therefore, outwardly indistinguishable from the 25% in which the fertilised reproductive cells are homozygotic, containing only red genes. The remaining 25%, finally, contain only white genes, and therefore, when bred in-and-in, continue to produce only white-flowering plants. We have, therefore, exactly the same ratio of 25%

Hereditary Stability and Instability

hereditarily stable (homozygotic) white-flowering offspring, 50% hereditarily unstable (heterozygotic) red-flowering offspring, and 25% hereditarily stable (homozygotic) red-flowering offspring. Owing to the dominance of red over white, however, the hereditarily unstable and the hereditarily stable red-flowering peas look exactly alike, and only when we breed further from these red-flowering hybrids do we find in the second generation that some of them contain heterozygotic reproductive cells.

B.—Now I really understand. But why have you chosen nothing but plants to illustrate the matter? Does not heredity abide by these Mendelian laws in the case of animals as well?

IN-BREEDING

A.—On principle, the processes of heredity are identical in all multicellular animals. (See Fig. 84.) In many plants, however, we have the advantage for investigatory purposes that it is easy to breed strictly in-and-in, so that with absolute certainty we can ensure self-fertilisation

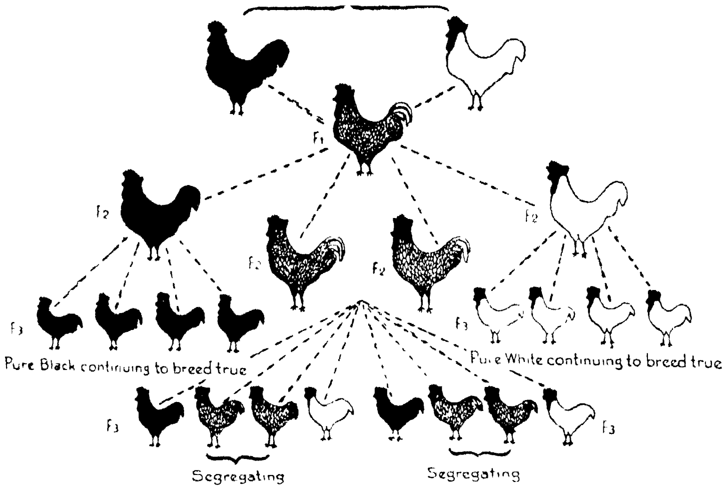
F1
F2
F2
F2
F2
F3
Pure Black continuing to breed true
F3
Pure White continuing to breed true
F3
F3
Segregating
Segregating

FIG. 84.—HEREDITY IN BLUE ANDALUSIANS. (After CASTLE.)

P, parental generation. From the crossing of a black hen with a white cock, or, conversely, of a white hen with a black cock, there arise in the first hybrid generation (F_1) only blue Andalusians. When we continue to breed from these blue Andalusians, there arise in the second hybrid generation (F_2) 25% black fowls, 25% white fowls, and 50% blue Andalusians. The black fowls breeding with black and the white fowls with white, continue to produce a pure black and a pure white strain respectively; whereas when the blue Andalusians breed with one another, they continue to segregate in the proportions 1 : 2 : 1. This exactly corresponds with what happens in the case of the white-flowering and the red-flowering four-o'-clocks.

JOHANNSEN

or, as Johannsen says, we can work with pure lines. However, since you want an example from the animal kingdom, I will give you one

THE COMMON OR GARDEN SNAIL

to illustrate the laws of Mendelian inheritance. Our common or garden snail (Helix hortensis) is met with in two stable hereditary varieties. The shells of one variety are self-coloured, those of the other variety are ornamented by dark bands. If we pair a banded snail with a self-coloured snail, we get in the first hybrid generation only self-coloured snails. When, breeding strictly in-and-in, we continue the experiment, in the second hybrid generation and in all subsequent generations, we find that 25% of the offspring are banded. These banded snails of the later generations, when bred in-and-in, breed true, producing always banded offspring. This case corresponds precisely with that of the red-flowering and white-flowering peas, the gene "self-coloured" being dominant over the gene "banded". The banded young are homozygotic, containing in their reproductive cells only the genes "banded" and breeding true, whereas of the 75% self-coloured snails only 25% are homozygotic, 50% being heterozygotic, and, when bred further, continuing to segregate in the ratio of 1 : 3 just as red-flowering and white-flowering peas.

B.—Hitherto you have always concentrated your attention upon one character. In most instances, however, the individuals we use in breeding experiments must differ from one another in numerous characters. How does heredity work in such creatures?

Inheritance of Several Pairs of Coupled Characters

A.—Of course that makes the analysis more difficult, since we have to attend to two, three, or more pairs of coupled characters. Nevertheless such instances are most instructive, for they show the independent assortment and the interchangeability of the individual genes, and prove that the various heritable parental qualities can appear in the offspring in all possible combinations. Although the issues are more complicated, the same principles are at work. For our understanding of the matter it will be enough for us to take the simplest possibility, and to study what happens when we have two different pairs of coupled characters. Let us say that we cross peas which have a Yellow-wrinkled seed-case with peas which have a green-Smooth seed-case. We are concerned, here, with two pairs of characters, Yellow-green and wrinkled-Smooth. The yellow tint of the seed-case of one parent and the smooth quality of the seed-case of the other parent are dominant; the colour green and the character wrinkled are recessive. What will the peas of the first hybrid generation look like?

All Possible Combinations of Heredity Factors Occur

B.—All the peas will be Yellow-Smooth, since all the fertilised ovules contain the paired characters Yellow-green and Smooth-wrinkled, and Yellow is dominant over green and Smooth over wrinkled.

A.—Good. Since, however, the two pairs of characters Yellow-green and Smooth-wrinkled which are brought together in the ovule during fertilisation segregate one from another in the maturation of the reproductive cells of the hybrid, are independently assorted, but in other respects behave exactly like the paired characters red-white, so, in this case, the hybrids form, not two, but four different kinds of reproductive cells. In accordance with the law of probability, there will be approximately the same number of each of these kinds. We have, therefore, various sorts of ovules and various sorts of pollen grains, one quarter of them containing the genes Yellow-wrinkled, one quarter Yellow-Smooth, one quarter green-wrinkled, and one quarter green-Smooth. The hybrid, therefore, forms as many sorts of different reproductive cells as there are possible combinations between the independently assorted and segregating genes. If we breed in-and-in strictly from these hybrids of the first generation, we are working with pollen grains and with ovules of four different kinds as far as their hereditary equipment is concerned. They can produce 4 × 4 = 16 different combinations in the act of fertilisation. The frequency with which these various combinations will be realised is, once more, dependent upon the law of probability. In order to make clear to yourself the various possibilities, the various ways in which these paired characters can be combined, draw a large square and divide it into 16 smaller fields. Over each vertical division you will write the hereditary characteristics of the pollen grains, using capital initials for the dominant and lower-case initials for the recessive characters. Thus, Yellow-Smooth, Yellow-wrinkled, green-Smooth, and green-wrinkled. In like manner you will write in horizontal series in the left-hand margin the four different characteristics of the ovules. If, now, you enter in each of the 16 squares the corresponding male and female combined characters, you will have all the combinations which can be obtained by a union of the four sorts of pollen grains with the four sorts of ovules. Since, however, Yellow is dominant over green and Smooth over wrinkled, you can also insert in each square what will be the aspect of the offspring resulting from each of these combinations. I have myself drawn the table for you, and you will see at once that in $\frac{9}{16}$ths of all the fields the dominant genes Yellow-Smooth are present in the fertilised ovules, so that $\frac{9}{16}$ths of the offspring must be Yellow-Smooth peas. Three times the gene Yellow (once homozygotic and twice heterozygotic) enters into combination with the homozygotic recessive character wrinkled, so that we get $\frac{3}{16}$ths of the peas with Yellow-wrinkled seed-cases. The same is true of green-Smooth; and here also the recessive gene green enters once homozygotically into combination with the dominant gene Smooth homozygotically and twice heterozygotically; so that another $\frac{3}{16}$ths of the offspring will be peas with green-Smooth seed-cases. In the right-hand lower field, finally, we find in the fertilised ovule that a green-wrinkled pollen grain has fertilised a green-wrinkled ovule, so that $\frac{1}{16}$th of the offspring contain homozygotically the recessive green-wrinkled genes, just as $\frac{1}{16}$th of the offspring contain homozygotically (upper left-hand corner) the two dominant genes Yellow-Smooth. Thus, as the outcome of our hybridisation, in $\frac{1}{16}$th of the cases and again in $\frac{1}{16}$th of the cases we have two hereditarily stable races, one of them with Yellow-Smooth seed-cases and one of them with green and wrinkled seed-cases. These will breed true. All the other results you can work out for

Pollen → Ovules ↓	Yellow + Smooth	Yellow + wrinkled	green + Smooth	green + wrinkled
Yellow + Smooth	Yellow + Smooth Yellow + Smooth YELLOW — SMOOTH Yellow = homoz. Smooth = homoz.	Yellow + wrinkled Yellow + Smooth YELLOW — SMOOTH Yellow = homoz. Smooth = heteroz.	green + Smooth Yellow + Smooth YELLOW — SMOOTH Yellow = heteroz. Smooth = homoz.	green + wrinkled Yellow + Smooth YELLOW — SMOOTH Yellow = heteroz. Smooth = heteroz.
Yellow + wrinkled	Yellow + Smooth Yellow + wrinkled YELLOW — SMOOTH Yellow = homoz. Smooth = heteroz.	Yellow + wrinkled Yellow + wrinkled YELLOW — WRINKLED Yellow = homoz. wrinkled = homoz.	green + Smooth Yellow + wrinkled YELLOW — SMOOTH Yellow = heteroz. Smooth = heteroz.	green + wrinkled Yellow + wrinkled YELLOW — WRINKLED Yellow = heteroz. wrinkled = homoz.
green + Smooth	Yellow + Smooth green + Smooth YELLOW — SMOOTH Yellow = heteroz. Smooth = homoz.	Yellow + wrinkled green + Smooth YELLOW — SMOOTH Yellow = heteroz. Smooth = heteroz.	green + Smooth green + Smooth GREEN — SMOOTH green = homoz. Smooth = homoz.	green + wrinkled green + Smooth GREEN — SMOOTH green = homoz. Smooth = heteroz.
green + wrinkled	Yellow + Smooth green + wrinkled YELLOW — SMOOTH Yellow = heteroz. Smooth = heteroz.	Yellow + wrinkled green + wrinkled YELLOW — WRINKLED Yellow = heteroz. wrinkled = homoz.	green + Smooth green + wrinkled GREEN — SMOOTH green = homoz. Smooth = heteroz.	green + wrinkled green + wrinkled GREEN — WRINKLED green = homoz. wrinkled = homoz.

yourself easily enough by studying the table. Here once more we see that the results are in strict conformity with the law of probability. If we look at the characters separately, we find that for each wrinkled pea there are three Smooth ones, and for each green pea there are three Yellow ones, so that we have the same ratio as among the dominant red-flowering and the recessive white-flowering races of peas. In like manner, here, we have a definite proportion of hereditarily stable offspring, whereas the remainder will continue to segregate when we breed from them. Thus by the hybridisation, the parental qualities are mingled and are grouped in such a way that all possible combinations among the characters to which we are attending in our hybridisation experiments manifest themselves in strict accordance with the law of probability. What I have been describing to you as regards two pairs of characters applies equally well to hybridisation when we are concerned with three, four, five, or even more pairs of characters. In the fruit-fly drosophila with which the most extensive experimental work upon genes has been done, about 500 independent hereditary characteristics have been noted, each of which is transmitted in strict accordance with Mendel's laws. In hybridisation experiments, therefore, we have a way, by crossing and recrossing, of mingling characters just as we please; producing hereditarily stable combinations, uniting or separating as we like, and thus producing new types of animal and plant from which we can breed true. Of course the control of the results and the process of selection become more and more difficult, the larger the number of paired characters with which we have to deal, inasmuch as, if pure races are to be bred, it is essential that the reproductive cells shall be homozygotic as regards this or that desired gene. In the case considered in the table we have, among the 16 combinations, obtained only four which are homozygotic in respect of both pairs of characters; but we can only recognise forthwith the new combination green-wrinkled, that is to say the pair with the two recessive characters, and from this only, therefore, can we proceed without more ado to breed a pure line. The second pair, with the homozygotic gene Yellow and the homozygotic gene Smooth, cannot, since Yellow and Smooth are dominant, be distinguished from the other 14 cases in which either the dominant gene Yellow or the dominant gene Smooth is present though heterozygotically. Only by prolonged and frequent recrossings can these genes be mendelised out in pure strains. For that reason, only such animals and plants are suitable for experiments in heredity as have numerous offspring and breed quickly, so that many generations of them can be obtained within a short time.

MENDEL AND CYTOLOGY

B.—Yes, I understand that; but I cannot yet see how or to what extent these experiments are accordant with the data of cytology and with the observed behaviour of the chromosomes during the reduction-division and during fertilisation.

A.—When you compare the breeding experiments with the data of cytology (which were unknown to Mendel) you will see how admirably the two fit into one another like the cog-wheels of a mechanism. (See Fig. 85.) But I will try to make the matter clear to you by a practical example. Let us suppose that the body-cells of four-o'-clock contain 8 chromosomes ; then we know that these 8 chromosomes comprise 4 pairs, one member of each pair deriving its hereditary equipment from the mother, and the other member its hereditary equipment from the father. Let us further suppose that in one of

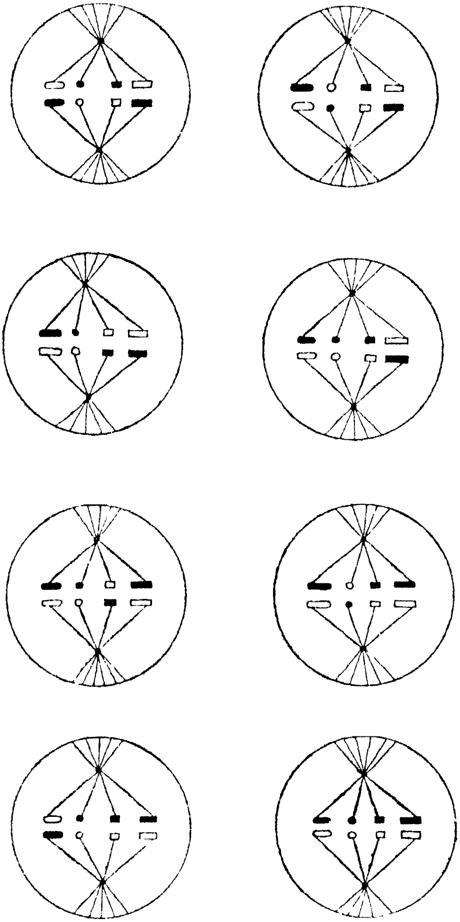

Fig. 85.—The Eight possible Ways in which, supposing a Species to have eight Chromosomes in its Body-cells, the Paternal and Maternal Chromosomes may be allotted to the Daughter-cells in the Reduction-division.

Thus, alike in the males and in the females of this species, there will be sixteen different sorts of gametes (spermatozoa or ova, as the case may be) varying one from another in their chromosome-content.

these chromosomes there is contained the gene for the colour of the flowers. We will denote these 4 pairs of chromosomes by letters, calling the chromosomes of the white-flowering four-o'-clock aa, bb, cc, WW, and the chromosomes of the red-flowering four-o'-clock aa, bb, cc, RR, using WW to denote the chromosome-pair containing the white-flowering gene and RR to denote the pair of chromosomes containing the red-flowering gene. Since in the reduction-division the maternal and paternal chromosomes separate, and the mature reproductive cells contain only half the ordinary number of chromosomes, the reproductive cells of the red-flowering stock will contain chromosomes abcR, and those of the white-flowering four-o'-clock will contain the chromosomes abcW. If we now cross the red-flowering with the white-flowering race, the fertilised ovule will once more contain 8 chromosomes comprising 4 pairs aa, bb, cc, RW. In the subsequent divisions and subdivisions of the egg-cells, these chromosomes always split longitudinally and are impartially allotted to the daughter-cells, so that all the body-cells of the first hybrid generation contain chromosomes aa, bb, cc, RW. Since the two chromosomes RW have equal capacity for coming into their own, in the first hybrid generation we have exclusively pink-flowering four-o'-clocks. In the reproductive cells of the first hybrid generation, however, during the reduction-division the paternal and maternal chromosomes separate once more, so that there arise two kinds of reproductive cells each containing 4 chromosomes; 50% of these having the red chromosome, and 50% of them the white chromosome. If you now breed strictly in-and-in from this first hybrid generation, you can obtain the following combinations:

Red ovule plus red pollen gives aa, bb, cc, RR = 25%
Red ovule plus white pollen gives aa, bb, cc, RW } = 50%
White ovule plus red pollen gives aa, bb, cc, WR }
White ovule plus white pollen gives aa, bb, cc, WW = 25%

Here, however, we have a strictly Mendelian segregation in the ratio of 25% red, 50% pink, and 25% white. You see, then, that the results of hybridisation experiments and of cytological research are strictly accordant and confirm one another mutually. We get the same conformity and mutual confirmation when we work with two or more pairs of characters.

Number of Chromosomes and of Genes

B.—How clear and simple these enigmatic processes of heredity become as soon as we understand the impulses which set the cog-wheels in motion. But there is still one more question I must ask you. If, of these mendelising pairs of heredity factors, each heredity factor is located in a particular chromosome, then there could be only so many segregating heredity factors as the animal or plant concerned has pairs of chromosomes. The more highly organised a living creature is, the more complicated the structure of its organs, the greater must be the number of heritable qualities. Just now, however, when you were speaking of cell-division, you said that the number of the chromosomes is not dependent upon complexity of organisation, and mentioned in exemplification that man has only 24 pairs of chromosomes in his body-cells, whereas a small crustacean has 62 pairs. The facts do not seem to me to square.

A.—You are quite right in drawing attention to this contradiction. It was only in order to simplify my account of the processes of heredity that I assumed an entire chromosome to be the carrier of a heritable quality. In reality every chromosome is the carrier of a number

Like Beads on a String

of mendelising genes, arranged in the chromosome like beads on a string. Experiments which it would take too long to describe have shown that a good many of the heredity factors united in a chromosome are transmitted as if we had to do with only one heredity factor.

Linked Inheritance

We say, in such cases, that these factors are linked, and we speak of linked inheritance. Much more commonly, however, do we find

Interchange of Genes

that there occurs an interchange of genes between a pair of chromosomes, so that the maternal and paternal genes assembled in a pair of chromosomes may be redistributed in any conceivable combination. (Refer back to Fig. 49.) Investigation has further shown that the largest chromosomes contain the greatest number of genes, just as a long string of beads contains more beads than a short one. Sometimes, too, it happens that, during the preliminaries to the reduction-division, the two partners of a pair of chromosomes appose themselves to one another crosswise, and that then, in the act of division, they will break where they intersect, half of one joining up to half of the other, so that the upper part of the maternal chromosome unites with the lower part of the paternal or conversely, and in this condition is transferred to the daughter-cells. (Refer back to Fig. 50.) In many cases we can actually determine the precise point in a chromosome in which a particular gene is situated.

What Characters Mendelise

B.—I should like to know what sort of characters mendelise.

A.—As I have already told you, in the case of the fruit-fly, to which the American investigator Morgan has devoted such close attention, we know of round about 500 characters that mendelise, and it is probable that all hereditary qualities are transmitted in accordance with Mendel's laws.

Human Heredity

B.—In that case, Mendelian laws must apply to human heredity ?

A.—Certainly they do. Of course, as far as man is concerned, owing to the length of human generations, averaging about thirty years, and owing to the small number of offspring in the human species, the analysis of Mendelian inheritance is far more difficult than in the case of the pea or the fruit-fly. We must have recourse to statistics, and to family histories. As far as human beings are concerned, Mendelian inheritance has been most clearly established in the matter of the transmission of morbid trends ; and chiefly in the case of one of a pair of characters (monohybrid inheritance). As far as man is concerned, little is known about dihybrid heredity, such cases as we have studied in the matter of Yellow-wrinkled and green-Smooth in the seed-case of the pea. Normally, in human heredity, linkage and the exchange of genes seem to be common. But I will give you a concrete example of how Mendelian notions can be usefully applied to elucidate human heredity in respect of the transmission of a disease from generation to generation.

HÆMOPHILIA

In a fair number of persons there is a lack in the blood of the substance which promotes its coagulation in cases of wounds. In such persons trifling wounds, such as the extraction of a tooth, may lead to fatal bleeding. You have probably heard that the son of the last tsar of Russia was what is called a bleeder. If a man suffering from hæmophilia marries a healthy woman, both his sons and his daughters are healthy. We should be apt to derive the impression that hæmophilia is not an inheritable disease. In reality, however,

HIDDEN GENES

we have to do with a recessive character, which only manifests itself when it is present homozygotically. When a hæmophiliac man has married a healthy woman, the germ-plasm of their apparently healthy children contains the gene of this sinister disease, just as, when we crossed a red-flowering and a white-flowering pea, the white gene was hidden in the germ-plasm of some of the red-flowering hybrids of the first generation. And, just as the white colour came to light once more in 25% of the offspring of the second hybrid generation, so when such an apparently healthy child marries a person with the hæmophiliac taint, among a certain proportion of the children of the pair the disease will come to light. It is thus transmissible by inheritance with a jump of several generations. But before I can make this matter clear to you I must explain the inheritance of sex, since hæmophilia is what is called a sex-linked disease.

BOY OR GIRL ?

B.—I have often been on the point of asking you why on the average there are about as many males born as females.

A.—As I have already insisted several times, the number of chromosomes in the body-cells of the individuals of any species is constant, being, for instance, 48 in man. During the reduction-division this number is reduced by half in the reproductive cells. A good while ago it was found that in fire-flies this law as to the number of the chromosomes applies only to the females. (See Fig. 86.) The female fire-fly has 24 chromosomes in its body-cells, whereas the male fire-fly has only 23. Further investigations showed that the fire-fly does not stand alone in this matter, for in a good many other creatures the males have one chromosome less in their body-cells than the females. For instance the common hen has 10 chromosomes, but the cock only 9; the cicada, 24 and 23; the opossum 10 and 9. Thus whereas in the females all the chromosomes are

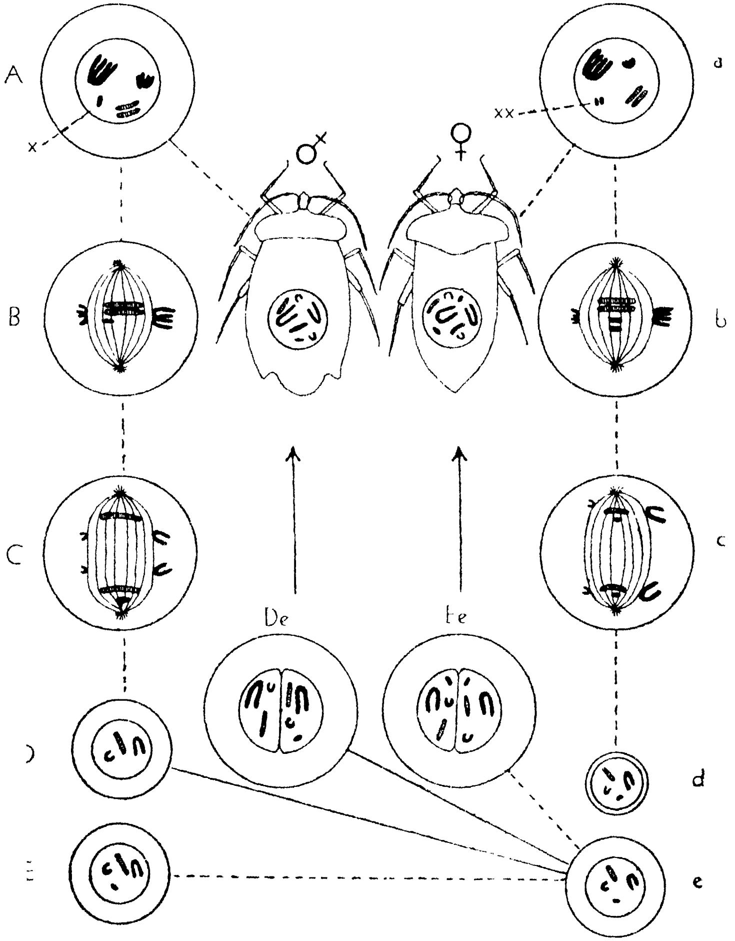

FIG. 86.—SEX-DETERMINATION IN FIRE-FLIES.

For the sake of clearness it is assumed that the male, which has only one X-chromosome, has 7 chromosomes in all (instead of 23), and that the female, which has two X-chromosomes, has 8 chromosomes in all (instead of 24). A, spermatogonium, with one X-chromosome; *a*, ovogonium, with two X-chromosomes; B and C, reduction-division of the spermatogonium, giving rise to two sorts of spermatozoa, viz. D, without an X-chromosome, and E, with an X-chromosome; *b* and *c*, reduction-division of the ovogonium, giving rise to only one kind of mature ova, viz. *e*, with an X-chromosome, and in addition to abortive ova or polar bodies, which are similarly constructed, but are foredoomed to perish. In fertilisation, the following combinations are possible: spermatozoon D (which has no X-chromosome) may fertilise ovum *e* (which has an X-chromosome before fertilisation, and will therefore have one after), this is the zygote De, and a male will result; or spermatozoon E (which has an X-chromosome) may fertilise ovum *e* (which has an X-chromosome before fertilisation and will now have two X-chromosomes), this is the zygote Ee, and a female will result.

arranged in pairs, the males of these species have an unpaired chromosome. Since the significance of this anomaly was not at first understood, the unpaired chromosome was called the X-chromosome. At length the puzzle was solved, and it became apparent that the enigmatic unpaired chromosome is responsible for the determination of sex. Whereas the maturation of the ovum proceeds normally, so that the mature ovum receives its full complement of chromosome pairs, during maturation of the spermatozoon two kinds of spermatozoa are formed, half of them containing an X-chromosome, and the other half lacking it. Thus, for the fertilisation of the ova, all of which are provided with X-chromosomes, there are spermatozoa to the number of 50% provided with a X-chromosome. Consequently, on an average, only 50% of the ova, when fertilised, have paired X-chromosomes, whereas the remainder must content themselves with an unpaired X-chromosome. Inasmuch as all the body-cells have the same chromosome content as the fertilised ova, and inasmuch as the males have an uneven and the females an even number of chromosomes, it is clear that females must proceed from the fertilised ova containing paired X-chromosomes and the males from the fertilised ova containing unpaired X-chromosomes.

THE X-CHROMOSOMES

B.—Now I understand how, in accordance with the working of the law of probability, there must always be about the same number of boys and of girls.

A.—There are also species in which both sexes have only paired chromosomes ; but in these among the males one of these pairs of chromosomes contains members of different sizes, these being the sexual chromosomes. (Refer back to Fig. 44.) Here also, in the males, there are produced two kinds of spermatozoa, half of them containing the large member of the pair of sexual chromosomes, and, when they fertilise the ova, producing females ; and the other half containing the smaller chromosome of the paired sexual chromosomes, known as the Y-chromosome, and producing, when they fertilise the ova, males. I should also mention that in most birds and most butterflies and moths, the males have a paired X-chromosome and the females an unpaired. In these creatures, therefore, there are produced only one sort of spermatozoa, but two sorts of ova. Substantially, however, the determination of sex depends upon the working of the same principle.

DISEASE AND SEX

B.—And now please explain to me how hæmophilia is linked with sex.

A.—The matter is simple. This disease is caused by a recessive morbific gene contained in the X-chromosome. Since the male has only one X-chromosome, which is not held in check by the corresponding dominant gene, the recessive factor comes into its own when his X-chromosome contains it. The woman, on the other hand, has two X-chromosomes, so that in her case one of her X-chromosomes may contain the recessive gene which produces hæmophilia, but it will not do her any harm. If the second X-chromosome contains the dominant opposing factor, she appears healthy, for a recessive factor does not manifest itself unless it be present homozygotically. Thus only when, by chance, as in the marriage of near kin belonging to a family tainted with hæmophilia, a daughter inherits two X-chromosomes both containing the hæmophilia-producing gene, will this disease manifest itself in her. Predominantly hæmophilia is a disease of males. In like manner as regards colour-blindness, the disease is dependent upon a recessive gene present in the X-chromosome. If a colour-blind man marries a healthy woman, all the children proceeding from this marriage will have normal sight. (See Fig. 87.) For the rest, transmission of colour-blindness runs on the same lines as that of hæmophilia.

Colour-Blindness

B.—I am afraid I have not quite grasped the situation, and should like you to explain to me the inheritance of colour-blindness in fuller detail.

A.—As I have already explained, the tainted father produces two kinds of spermatozoa, 50% of them lacking an X-chromosome, and 50% of them provided with an X-chromosome with which the gene producing colour-blindness is linked. The healthy mother, on the other hand, produces only one kind of ova which all contain the X-chromosome and linked therewith the gene for the production of normal sight. Since from the union of a spermatozoon devoid of the X-chromosome with the ovum a boy results, the son will inherit from the mother only the normal-sighted X-chromosome ; that is to say in this son the morbid taint of the father will have completely disappeared from the hereditary equipment. If they marry healthy women, their children will have normal sight. On the other hand, the remaining half of the spermatozoa thus containing the X-chromosome, female-producing and having the gene for colour-blindness linked with them, will produce daughters having, not only the normal-sighted X-chromosome of the healthy mother, but also the colour-blind X-chromosome of the colour-blind father. Inasmuch as, however, the gene for normal sight is dominant over the gene for colour-blindness, the fertilised ovum being heterozygotic, i.e. combining the characters for colour-blindness and for normal sight, these daughters are normal-sighted, although they harbour the morbid X-chromosome in their cells. If such an apparently healthy heterozygotic girl marries a healthy normal-sighted man, half of her sons will be colour-blind, while her daughters will all be apparently healthy, and in reality half of these daughters will have received two X-chromosomes containing the genes for normal sight, but the remaining half of the daughters will be heterozygotic, and will each of them contain a colour-blind X-chromosome in their body-cells. Is the matter now clear to you ?

B.—Not quite.

A.—Well, we will analyse the case yet more closely. The mother

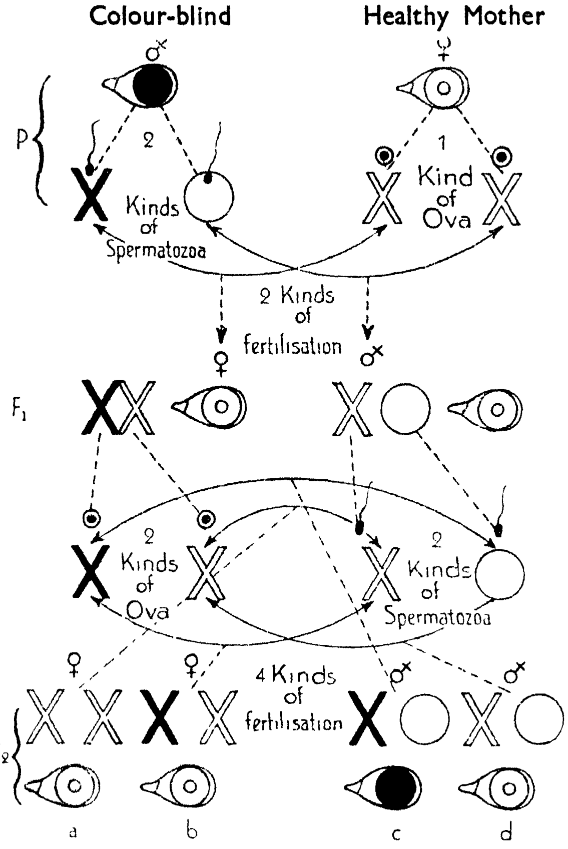

FIG. 87.—SEX-LINKED INHERITANCE OF COLOUR-BLINDNESS.

♂, symbol for father ; ♀, symbol for mother ; P, parental generation. The colour-blind father generates two kinds of spermatozoa, half of them having the sex-determining X-chromosome, with which the gene for colour-blindness is linked, and half of them (denoted by ⊙) being without this chromosome. The healthy mother generates only one kind of ova, all of them containing an X-chromosome. F1, first filial generation. An ovum which has been fertilised by a spermatozoon containing an X-chromosome develops into a female whose cells include the gene for colour-blindness that is linked to the paternal X-chromosome, but colour-blindness does not manifest itself in this female, since the gene for colour-blindness is recessive, and can only become active in a homozygotic organism. Boys free from colour-blindness and from hereditary taint thereto, develop out of ova fertilised by a spermatozoon that does not contain an X-chromosome. The hereditarily tainted daughters of the first filial generation (who themselves have normal colour vision) generate two kinds of ova, 50% of which contain the paternal X-chromosome (to which colour-blindness is linked), and 50% only the healthy maternal X-chromosome. The sons free from hereditary taint also generate two kinds of reproductive cells, 50% of which contain the untainted maternal X-chromosome, while 50% have no X-chromosome at all. If a girl with normal colour-vision but having the hidden taint, marries a man free from taint, four kinds of fertilisation are equally probable : 1, an ovum with a healthy X-chromosome may be fertilised by a spermatozoon with a healthy X-chromosome, producing a daughter of the second filial generation who will be free from hereditary taint (*a*) ; 2, an ovum with a healthy X-chromosome may be fertilised by a spermatozoon which has no X-chromosome, and will then produce an untainted son (*d*) of the second filial generation ; 3, an ovum with a tainted X-chromosome may be fertilised by a spermatozoon with a healthy X-chromosome, and will then produce an outwardly healthy but inwardly tainted daughter (*b*) ; 4, an ovum with a tainted X-chromosome may be fertilised by an ovum having no X-chromosome, and will then produce a son (*c*), colour-blind, and capable of transmitting the hereditary taint.

who in respect of colour-blindness is heterozygotic has in her body-cells one normal and one colour-blind X-chromosome. During reduction-division of her reproductive cells, the normal and the colour-blind X-chromosomes segregate; there arise two kinds of ova, half of which are provided with normal X-chromosomes, and the other half with colour-blind X-chromosomes. The healthy father also produces two kinds of spermatozoa, half of which have normal, daughter-producing X-chromosomes, and half of which have no X-chromosomes and produce boys. Here, too, we have four possibilities of fertilisation:

Spermatozoon with normal X-chromosome plus ovum with normal X-chromosome—normal daughter free from taint.

Spermatozoon without X-chromosome plus ovum with normal X-chromosome—normal son free from taint.

Spermatozoon with normal X-chromosome plus ovum with colour-blind X-chromosome—normal daughter with hereditary taint.

Spermatozoon without X-chromosome plus ovum with colour-blind X-chromosome—colour-blind son with hereditary taint. (See Fig. 87.)

B.—Now I understand the process. It is just as it was with the red-flowering and white-flowering peas, only here the recessive factor colour-blind is linked with the sex-determining X-chromosome.

FAMILY DISEASES

A.—These two examples will have been enough to show you how important it is for the public health and for the future of our race that before marriage the family history of bride and bridegroom should be carefully studied as regards this matter of hereditary illness. If the same hereditary disease has been present in the ancestry of both families, such a marriage is inadmissible, for it is fairly certain that some of the children that issue from it will be diseased. But the ways of nature are far more complicated than might appear from the simple examples I have given you. There are, for instance, certain genes which are apt to be linked with other genes and which can exist only in the heterozygotic state. If two such genes come together in the fertilised ovum, the resulting embryo will perish before birth, or there will arise non-viable offspring, which will die in early youth. In this way there sometimes ensue deviations from the classical Mendelian ratios, simulating exceptions to the rule. For example, canaries with a crest are heterozygotic in respect of the dominant gene for the production of the crest, this meaning that their body-cells also contain the recessive gene for the lack of a crest. If I cross two crested canaries, I shall always get $\frac{2}{3}$ crested birds and $\frac{1}{3}$ uncrested birds; whereas, according to the Mendelian rule, I should expect 75% crested birds and 25% uncrested. This is because the 25% of the crested birds which contain the gene for the pro-

LETHAL GENES

CRESTED AND UNCRESTED CANARIES

duction of the crest homozygotically, die during the first days of life. We find a similar instance in the case of a heterozygotic yellow race of mice in which a lethal gene is associated with the gene for the production of yellow, so that 25% of the offspring, homozygotic yellow mice, always die in utero. But I have given you enough examples. My reason for this cursory outline of the modern doctrine of heredity was that you might be able to understand the inferences we shall draw to-morrow for the application of the theory of selection and the doctrine of heredity to eugenics.

B.—I should like to ask you one last question.

A.—Go ahead.

B.—In the crossing of white-flowering and red-flowering four-o'-clocks, in the second hybrid generation there occurs a segregation of the grand-paternal genes, red and white, so that at least 50% of the offspring are of the primitive pure white and pure red types. Does anything of that kind occur in the case of mixed human races? Suppose a white man marries a negress, surely the children of such a union are all of the mixed mulatto type. When mulattos intermarry and procreate, do we find in a certain percentage of the offspring a segregation of the genes so that some of these children are pure negroes, others pure whites, and only 50% mulattos?

A.—I think you should know for yourself that this cannot be so. In our experiments on four-o'-clocks we chose for our hybridisation experiments plants that differed from one another only in respect of one character, the red flowers and the white flowers; and the genes producing red flowers or white flowers segregated, on continued breeding, in the regular proportions of 1 : 2 : 1. But when a crossing occurs between Europeans and negroes, we have to do with innumerable different characteristics, which are mingled with one another, and form many paired characters. Each of these paired characters, no doubt, mendelises strictly; but since the individual pairs of characters are independent of one another, it would be a remarkable chance that could lead to a complete segregation of the paternal and maternal hereditary equipments in subsequent generations. No doubt in many of the offspring, in the course of the generations, we shall find that the white paternal equipment will be more manifest, and in others the black maternal equipment, so that some of the descendants will have a predominantly European and others a predominantly negroid aspect; but the children of these specimens will be just as likely to throw back to the other type. The example I gave you of crossings where there were two or three pairs of characters to deal with showed you how difficult it must be to mendelise out the original races in a pure form. In view of the numberless independent genes carried by two such different human races, it would be fruitless were we to try to breed out from the resulting mulattos pure white or pure black types. What has thus been once mingled, cannot be segregated out again in many, many generations.

TWENTIETH EVENING

EUGENIC APPLICATIONS

Fall in the Birthrate

A.—In view of all that you have heard about the value of selection in improving breeds and about the working of heredity, what do you regard as the greatest peril that menaces the European peoples ?

B.—The catastrophic fall in the birthrate, which, Russia excepted, is obvious in all European countries. Whereas in 1875, in Germany, per 1000 inhabitants there were about 40 births every year, in 1929, the number of births had fallen to 18. As far as I know, the fall continues. But if a species is to maintain its numbers, each couple of parents must bring up at least two children to attain the age of reproduction. In the '80's of the last century, among Germans there were, on the average, about five children to each marriage ; but according to the latest statistics I have seen there are now only two children per marriage. Since a considerable percentage of our people remain unmarried, and since, although infantile mortality has been considerably reduced, a number of males and females die before attaining the age of reproduction, it is obvious that the Germans, if the revolt against bearing and bringing up children continues to spread, will cease to exist in a comparatively short time. In this respect, Asiatics and negroes have far better chances of race-survival. Spengler's warning that the civilisation of Europe and America would go down before the onslaught of the yellows and the blacks unless the white races as a whole recognised the imminent peril and saw to it that a sufficient number of offspring were born and reared, must not be regarded as scaremongering. (See Fig. 88.)

There are Graver Perils

A.—You are quite right in pointing to this grave danger, but there are causes at work which are perhaps yet more menacing to our existence as a lordly people.

B.—What is this greater peril of which you speak ?

Dysgenic Influences at Work

A.—Counter-selection, the artificial preservation of the less valid elements of our nation at the cost of the better specimens.

The World War and the Struggle for Existence

B.—You are referring to the devastations caused by the World War, I suppose. But surely the struggle for existence works, in nature at large, by eliminating the less fit and by the survival of those individuals who are best adapted to the conditions of existence? Does not this lead to the better health and to the higher development of the species?

POSITIVE (EUGENIC) SELECTION UNDER NATURAL CONDITIONS

A.—You cannot compare the working of the struggle for existence under natural conditions with the effects of a modern war. Indeed, people are apt to apply the term "struggle for existence" too literally. It is not mainly by a fierce and crude struggle of animals one with another that nature eliminates weakly individuals. What happens is, rather, that among the members of a species there goes on a powerful peaceful competition for food and the other necessaries of life; and the different species inhabiting any area also compete with one another within reasonable limits. Since every species brings many more offspring into the world than can secure a sufficiency of food and proper shelter, the most vigorous and most intelligent of the young have the best chance of surviving and of transmitting their hereditary equipment to posterity; whereas weaklings die prematurely of starvation, or are destroyed by the enemies that prey upon them, or (among social animals) are killed by their fellows. Thus a positive (eugenic) selection is continually going on.

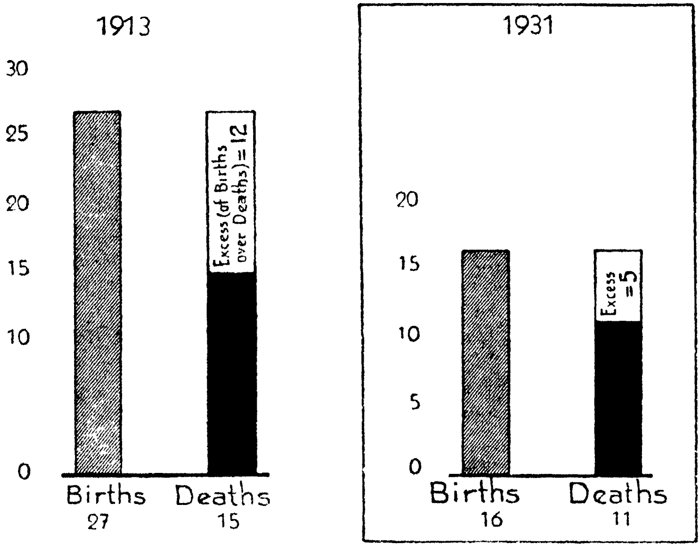

FIG. 88.—ANNUAL NUMBER OF BIRTHS AND DEATHS PER THOUSAND INHABITANTS.

WAR DOES NOT STRENGTHEN LIKE A FERRUGINOUS BATH, BUT IS DYSGENIC

The World War, on the other hand, weeded out many of the best elements of our people, the most courageous, those who were readiest to stake their lives. Our officers on active service were mainly recruited from the nobility and the upper bourgeoisie. No less than 25% of them were left dead on the battlefields, and an equally large percentage must have perished from illness or from wounds. Most of these were young men who were withdrawn from the possibility of perpetuating their like. If, as is generally admitted, during the last century France has fallen backward a good deal in her cultural achievements, this is mainly ascribable to the expulsion of the Huguenots (who were among the most intelligent members of the population) and to the terrible losses of life during the Revolution and the Napoleonic wars. Far from being " a ferruginous bath for the nations ", war, modern war, insofar as it exerts a selective influence, is, as Lenz insists, " a force that makes for the breeding of cowardice and dishonour ".

B.—The difference you describe between the struggle for existence under natural conditions and under the conditions of modern warfare had never occurred to me.

Mistaken Humanitarianism

A.—No less destructive than war to the hereditary efficiency of a nation is a mistaken humanitarianism which regards the individual as more important than the community. This, likewise, exerts a dysgenic influence, contributing to the preferential survival of diseased and invalid elements, which would, under natural conditions, have been eliminated before they attained an age at which they could transmit their tainted hereditary equipment to posterity. No doubt

Effect of Pestilences

we have many reasons to congratulate ourselves upon the fact that medical science, through the discoveries of its champions like Robert Koch, Pasteur, Roux, Behring, and others, has been so successful in the fight against such grave infectious diseases as cholera, plague, typhus, typhoid, smallpox, diphtheria, etc., so that in great measure these diseases have ceased to exist in civilised countries. Since, however, on the average the pestilences in question prevailed most abundantly among the weaklings of a nation, whilst the most vigorous and most healthy escaped them, hygiene and preventive medicine has been a two-edged weapon. Bringing blessings in its train, preventive medicine has also done harm, at any rate bodily harm, by favouring counter-selection.

B.—Still, it would be impossible to throw away the achievements of medical science and to favour a return of positive selection by smallpox, plague, and cholera.

A.—Of course it would. But once we recognise the danger, we must seek for means of counteracting these undesirable effects. The means do in fact exist, and we shall consider them presently.

Tuberculosis and Selection

B.—Instead of smallpox and cholera, tuberculosis now rages among our people. Before the War, I believe, 15% of all deaths in Germany were ascribed to this sinister disease.

A.—Yes, the crowding of human beings into great cities, bad housing conditions, the lack of fresh air and of sunlight, led to an enormous increase in tuberculosis, which especially strikes down its victims among the proletarianised strata of the population, so that (as of course you know) in the German idiom it is spoken of pre-eminently as " the proletarian disease ". According to the figures published by the Statistical Office of the town of Bremen in the year 1910, among well-to-do circles of the population per 10,000 inhabitants of ages ranging from 15 to 30, there died of pulmonary tuberculosis 2 ; in the lower-middle class, 10 ; and among the poorest of the poor, 32. Of course it is sad that social need should favour the incidence of this terrible disease. On the other hand, it is unquestionable that tuberculosis flourishes chiefly among the less fitted, and thus exerts a positive selection, similar to that which formerly resulted from the pestilences previously mentioned. Of late, the mortality from tuberculosis has been considerably reduced, not only thanks to improved hygienic conditions, the open-air treatment of consumption, etc. ; but also, as Pearson insists, to a gradual dying out of the families especially predisposed to tuberculosis, and to the consequent acquirement by the population at large of a natural immunity to the disease. It is well known that infectious diseases freshly introduced into a country rage far more fiercely among the population than in lands where this same disease has already been prevalent for centuries.

NATURAL IMMUNITY

B.—Yes, that is made plain enough by the terrible mortality from syphilis among negroes, and among the South Sea islanders when the malady was introduced into the South Seas by European mariners, whereas we Europeans have already acquired a considerable resistance to this malady. A few decades ago, measles was introduced into the Fiji Islands for the first time, and was as virulent there as the Black Death.

DANGERS OF VENEREAL DISEASE

A.—You are right in saying that the European populations have acquired a certain measure of resistance to venereal diseases, but nevertheless, from the racial hygienic standpoint, these diseases remain a great peril. It is probably an underestimate rather than an over-estimate to say that even to-day no less than 25% of all men in these parts of the world have during their lifetime at least one attack of a venereal disease. The fact that syphilis causes frequent abortions, and that in women what is called " one-child sterility " is an almost typical result of gonorrhœa, makes these diseases contribute extensively to the decline in the birthrate. Since, moreover, the most vigorous and most dare-devil men are those most exposed to venereal infection, venereal diseases exercise a marked dysgenic or counter-selective influence, and must therefore be combated most energetically by the diffusion of knowledge, by an increase in the sense of responsibility, and by hygienic measures. Even more serious is the increase

LUNACY AND FEEBLE-MINDEDNESS

in mental defect and disease. To-day the number of lunatics kept in restraint in the German Reich is more than 300,000. But it is not these graver cases of mental disorder, herded in asylums, and therefore excluded from the possibility of reproducing their kind, which constitute the greatest danger to the race. Far more serious, from this standpoint, are the slighter cases of feeble-mindedness, persons who remain at liberty, procreate children, and transmit their morbid taint. According to Lenz's estimate, 25% of all newborn children must be classed as feeble-minded or at least mentally below par. Fortunately natural selection gets to work upon such elements, and weeds out a great proportion of the mentally defective during the early years of life. But this selection does not suffice to preserve the race from damage to its hereditary equipment, seeing that, of our 65,000,000, almost 1,000,000 must be regarded as feeble-minded, and another 6,000,000 as mentally below par. In the United States, where similar conditions obtain, the various State governments have long since taken measures for the sterilisation of habitual criminals and persons suffering from grave mental taint, so that they may be prevented from reproducing their like. (See Fig. 89.) In Germany, at long last, a similar law for the hindering of the spread of hereditary taint has been enacted.

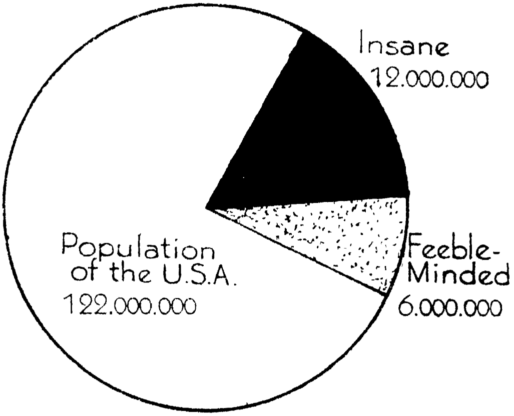

FIG. 89.—THE INTELLECTUALLY INFERIOR PART OF THE POPULATION OF THE U.S.

About 10% of the whole adult population undergo at some period of life a mental breakdown which unfits them for work. The additional 5% are kept backward through intellectual debility.

B.—It seems to me that castration for such purposes, castration with all its grave bodily and mental consequences, is a cruel infringement of individual rights.

STERILISATION THE REMEDY, NOT CASTRATION

A.—I am not talking about castration, about a removal of the reproductive glands, but about sterilisation, which merely deprives

A.—Yes, the crowding of human beings into great cities, bad housing conditions, the lack of fresh air and of sunlight, led to an enormous increase in tuberculosis, which especially strikes down its victims among the proletarianised strata of the population, so that (as of course you know) in the German idiom it is spoken of pre-eminently as " the proletarian disease ". According to the figures published by the Statistical Office of the town of Bremen in the year 1910, among well-to-do circles of the population per 10,000 inhabitants of ages ranging from 15 to 30, there died of pulmonary tuberculosis 2 ; in the lower-middle class, 10 ; and among the poorest of the poor, 32. Of course it is sad that social need should favour the incidence of this terrible disease. On the other hand, it is unquestionable that tuberculosis flourishes chiefly among the less fitted, and thus exerts a positive selection, similar to that which formerly resulted from the pestilences previously mentioned. Of late, the mortality from tuberculosis has been considerably reduced, not only thanks to improved hygienic conditions, the open-air treatment of consumption, etc. ; but also, as Pearson insists, to a gradual dying out of the families especially predisposed to tuberculosis, and to the consequent acquirement by the population at large of a natural immunity to the disease. It is well known that infectious diseases freshly introduced into a country rage far more fiercely among the population than in lands where this same disease has already been prevalent for centuries.

NATURAL IMMUNITY

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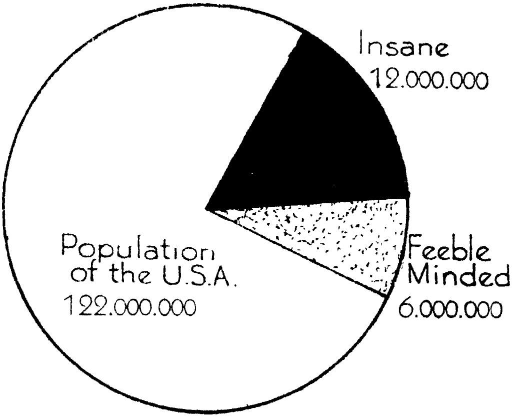

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STERILISATION THE REMEDY, NOT CASTRATION

A.—I am not talking about castration, about a removal of the reproductive glands, but about sterilisation, which merely deprives an individual of the power of reproducing his like, without impairing his other bodily or mental capacities in any way whatever. In men, especially, sterilisation is a comparatively trifling operative intervention. A small segment of the vas deferens is excised on both sides, but the testicles are left intact. The semen can no longer be evacuated, but the hormonal activity of the reproductive glands, which is essential to bodily and mental wellbeing, remains unimpaired. The patient recovers from the little operation within a very few days. The corresponding operation in women is somewhat more difficult, but their health and wellbeing are not in any way imperilled. Such sterilised persons remain fully capable of performing the sexual act, with the only restriction that they cannot procreate. From the outlook of the racial hygienist, there is no reason why hereditarily tainted persons who have been sterilised should not marry. As for what you say about a cruel infringement of individual rights, the general welfare is an over-riding privilege. Is it not far more cruel to look on unmoved while hereditarily tainted persons bring unfit children into the world, children who will never be anything but a burden to themselves and others ? Is it not far more humane, by intervention as above described, to put an end to the intolerable suffering of hundreds of thousands of married couples, to which it is a continual regret that they have brought such children into the world ?

AMERICAN EXPERIENCE

B.—What has been the experience of the United States in the matter of these sterilisation laws ?

A.—Down to January 1, 1933, the operation had been performed on 6999 men and 9067 women. The Human Betterment Foundation of California maintains the following theses as regards the eugenic conditions of sterilisation : 1. The only effect is the prevention of parenthood. 2. The patient is not in any way desexualised. 3. The operation is protective, not punitive, so there is no stigma of humiliation. 4. The sterilised patients approve the operation. 5. It is also approved by all their families and their friends. 6. Doctors and other experts who, during the past twenty-five years, have come into contact with sterilised patients are also united in their approval. 7. Sterilisation has enabled many patients who would otherwise have had to be kept in institutions for the rest of their lives, to return to their homes, thus helping instead of hindering family life. 8. It prevents the birth of children who would have to be brought up by mentally defective parents or by the State. 9. It relieves the taxpayers of a great burden, and enables the State to care for many more patients than would otherwise receive attention. 10. It has already led to a notable decline in offences against morality. 11. It has enabled numerous hereditarily tainted persons to marry and to lead what is in most respects a normal life—persons who, but for sterilisation, ought never to have been allowed to marry. 12. It is an effective and indispensable means for preventing racial degeneration.

NUMBER OF PERSONS UNFIT FOR PARENTHOOD

B.—Is the inheritance of such diseases, the hereditary transmission of such taints, really such a peril to the race? Surely they affect no more than an insignificant proportion of the population?

A.—Remember the figures I have already given you as regards the proportion of mental defectives among the population, and you will see that it is by no means insignificant. Grotjahn, a well-known eugenist, who happens also to be a social democrat and whose testimony therefore in this respect is all the more weighty, estimates the hereditarily unfit members of our population as numbering more than 20 millions; while Lenz writes of round about 15 millions of persons who, for social and eugenic reasons, ought to be debarred from propagating their kind. But even if the community were to protect itself by only sterilising the worst cases, habitual criminals, persons with grave mental disorder, and the typically feeble-minded, the good effect upon the general capacity and health of our population would become manifest within a very few decades.

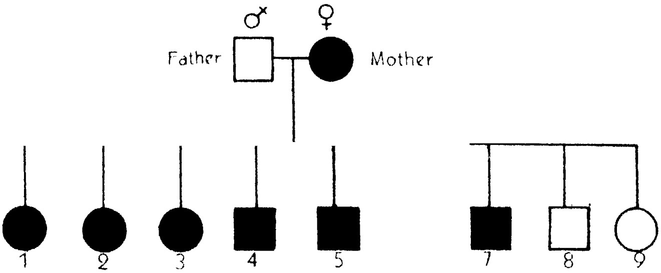

FIG. 90.—HEREDITARY TRANSMISSION OF MANIC-DEPRESSIVE INSANITY. (After GUYER.)

Squares, males; circles, females. White, normal; black, diseased. From the marriage of the healthy father with the diseased mother issued nine children. Four were daughters, and of these the youngest (the ninth child) died before reaching the age of three. The three eldest children, daughters, all suffered from manic-depressive insanity; of the five sons, only two escaped.

B.—Are there not data to show the hereditary transmission of especially bad or especially good trends in a family for several generations?

ADA JUKE

A.—Certainly there are. Since in the United States the importance of eugenics was earlier recognised than in Europe, the Americans have stolen a march upon us in such investigations. Doogdale and Easterbrook trace the history of a hereditarily tainted family from the year 1740 onward. They were the descendants of a woman named Ada Juke who belonged to the dregs of the population. Down to the present time these descendants number 2820, of which a large majority have been defective in one way or another. Of the 1250 Jukes still living in the year 1915, Easterbrook found there were 464 prostitutes, 118 criminals, 170 beggars, 129 occupants of poor-houses, and 181 habitual topers. There were also a great many weak-minded persons. A striking contrast to the Jukes is offered by the

THE EDWARDS FAMILY

Edwards family, who trace their lineage to the famous Jonathan Edwards, a man of outstanding intelligence. Down to the year 1900, his descendants numbered 1394 persons. Among the male members of the family, Winship found there had been 65 university professors, 13 presidents of universities, 60 medical practitioners, 100 parsons, 75 army officers, 60 noted writers, 130 lawyers, 80 higher officials, as well as a great many widely known statesmen and industrials.

B.—These are certainly striking instances of the power of heredity, and I cannot but agree with you that a nation must take measures against the spread of hereditary taint.

SPECIAL ADVANTAGES FOR PERSONS EXCEPTIONALLY FITTED FOR PARENTAGE

A.—That is not enough. At the same time the State must support and care for those whose hereditary equipment is untainted, and must see to it that they receive material advantages which will enable them to procreate and rear the largest possible number of children. From what you know of the Mendelian laws of heredity it must be plain to you that an especially favourable hereditary equipment in the father or the mother will not make itself apparent in all the offspring, so that the prospect that a child inheriting the desirable

QUANTITY AND QUALITY

qualities will be born will be greater in proportion to the number of children. As Lenz insists, it is a disastrous error to suppose " that a limitation of the quantity of children is likely to improve their quality. . . . The only way of increasing the proportion of children with a good inheritance, children of good quality, is to increase the quantity of births among the good stocks." If a couple of parents rear only one or two children they must not expect to find that in these children their own good genes will necessarily come together and produce a better type than their own ; but they may have good grounds for such a hope as regards one among many children. For instance, Werner von Siemens was the fourth child of 14 ; Kant, the fourth of 9 ; Schubert, a thirteenth child ; Benjamin Franklin, a seventeenth child. If the modern two-child system had been practised in their days, the geniuses I have named, to whom the world owes so much, would never have been born. Famous as

PROTESTANT PARSONAGES

" quiverful " houses have been Protestant parsonages ; and it is amazing to note how many of our musicians, imaginative writers, and thinkers, derive directly or indirectly from such a parsonage. If, as seems plain, the Catholic portion of our population has produced a smaller percentage of notable persons than the Protestant, this is probably ascribable to the celibacy of the clergy, whereby a notable part of the most gifted among our men is excluded from reproduction. In earlier times it was the pride of our best families to bestow a large number of children upon the world. A typical example is that of the famous mercantile and noble family of the Fuggers of Augsburg. The arch-progenitor of the princely line, Jacob Fugger, who died in 1468, had 19 children ; Georg Fugger had 20 children ; and Albert Fugger, who was twice married, had 21. To-day most of our old noble and well-to-do bourgeois families have

Extinction of Old Families

died out or are in course of dying out. Of the 20,000 noble families that existed in the twelfth century, only about 800 remain at the present day. But the good old bourgeois is also disappearing with terrible rapidity. In Mannheim, alone, according to Schott's data, during the last hundred years 2538 of the 3081 old burgher families have died out in the male line.

B.—Do you regard that as so great a misfortune for the race ? The place of worn-out old families is taken by young and vigorous families with an unexhausted hereditary equipment, derived from other strata of the population. Such a restratification is surely most desirable.

Inequality of Human Beings

A.—You would be right if the bodily and mental hereditary equipment were equally good in all strata of the population. But the equality of man, as maintained especially by Marx and his disciples, is a fiction. The nobility and the higher bourgeoisie did not achieve and retain their leading position simply through material advantages or the favour of fortune, but because their hereditary equipment fitted them for such a position. Although human beings of any

The Termite State

race or nation look very much alike, they are, from birth onwards, as different in respect of their endowments and capacities as the multiform individuals of a termite State. A worker-termite, which has remained in a juvenile developmental condition adapted to the tasks it has to perform, would never put in a claim to become a warrior-termite, since it lacks the bodily and mental faculties fitting it for such an occupation. Among human beings, most of them are foolish enough to believe themselves competent for any occupation. If they find themselves in a socially inferior position, they regard this as an outcome of the injustice of destiny and of birth. Their dissatisfaction depends upon a false judgment of values. How erroneous it is to

Not Lower or Higher, but Simple or Complex

speak of lower and higher species, instead of simpler and more complex species ! It is no less erroneous to speak of lower and higher classes. For the nation and the State, the workers and the peasants are quite as necessary as the mercantile classes and the intellectuals. But just as, in general, a man who is fitted for the life of an intellectual would make a poor job of it as a peasant or a manual worker, so do peasants and manual workers fail when called upon to fulfil the duties of an intellectual.

B.—I think your premises are unsound. In my view, among the peasants and the workers there are just as vigorous intellectual powers as among those who are called the upper classes. If the children of the former received equal advantages from the first, they would achieve quite as much in the intellectual domain as do the children of university professors, high officials, and army officers.

LIKE EDUCATION DOES NOT PRODUCE EQUALITY

A.—I do not doubt that exceptionally talented individuals appear from time to time among the peasants and the manual workers, and rise out of their class. The old families, too, rose long ago to their present positions because they were choice specimens of the populace. But their valuable hereditary equipment was transmitted to their descendants, and has become part of the spiritual capital of our nation which works for the advantage of the whole. This hereditary tradition (in the derivative sense of the term tradition) is undeniable. Unquestionably, too, there are persons of great talent among other strata of the population ; but they are isolated instances, and are capable of climbing out of the ranks. In any case statistics, which can alone give us accurate information in these matters, do not square with your contention. Promoted by such notions as those you have just

SCHOOLS FOR GIFTED PERSONS

been advocating, schools for gifted persons were established in many of our big towns, to provide a better education for talented children from the elementary schools. The general experience was that only a very few children belonging to the lower classes of the population were capable of a higher degree of culture. Extraordinarily interesting are the investigations of Terman, who applied stringent intelligence-tests which showed exceptional intellectual capacity in 642 among 12,000 Californian school-children. On further inquiry he found that by far the larger number of these talented children sprang from the upper classes. As to the professions of their fathers, 400 of them were university professors, industrials, and men in a large way of business ; nearly 200 of them were the sons of teachers, or business men carrying on operations on a smaller scale ; 32 were the sons of small tradesmen and manual workers ; 22 were the sons of skilled workers ; and only one was the son of an unskilled labourer. As Lenz writes : " From these figures we learn that a university professor or man in a large way of business has 400 times as good a chance of procreating a genius as has a man belonging to the class of unskilled

1000 : 1

workers." Indeed, seeing that persons belonging to the upper classes have, in general, fewer children than those belonging to the lower, we may say that the chances are really 1000 to 1. At Lenz's suggestion, Prokein made inquiry as to the social origin of 634 feeble-minded charity schoolboys in Munich, with the following results. Only

0·8% sprang from the intellectuals or upper professional, industrial, and mercantile strata; whilst about 98% sprang from the lower middle-classes and from the skilled and unskilled classes of workers. But I will not weary you with statistics. You must take it from me that everywhere such inquiries have led to similar results. To quote Lenz once more: "It is impossible to increase the number of the genuinely cultured by external educational influences, for the foundations of true culture lie in the hereditary equipment."

Decline in Cultural Level

B.—If that be so, the dying out of upper-class families must lead to a continual decline in the number of those who are truly cultured, and must lower the cultural level of the population as a whole.

Rise and Fall in the Social Scale

A.—Yes, this danger is a reality. Lenz makes it very vivid in a diagram he publishes. (See Fig. 91.) The upwardly directed arrow in triangle A indicates that social rise preponderates over social fall; whereas the downwardly directed arrow in triangle B indicates the opposite. If the families in the upper social strata reproduce themselves more slowly than those in the lower strata, to begin with, social rise predominates over social fall; but a further consequence is a decline in the average cultural level of the population. If, on the other hand, the families of the upper stratum procreate more rapidly than those of the lower stratum, then social fall will preponderate over social rise, but the average cultural level of the population will increase. According to data published by the German Statistical Bureau, on the supposition that the present birthrate averaging two children per marriage continues, the German population will die out within five generations. If we suppose that among the more fit the present two-children system or one-child system will persist as against the four-children system among the less fit, in the same period of 150 years, the percentage of the more fit will have fallen to 2, while the percentage of the less fit will have risen to 98.

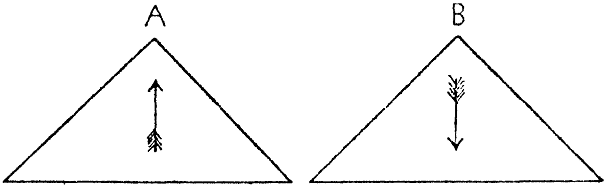

FIG. 91.—DIAGRAM ILLUSTRATING RISE AND FALL IN THE SOCIAL SCALE. (After LENZ.)

A, the families in the upper social strata procreate less abundantly than those in the lower: first consequence, that social ascent predominates over social descent; second consequence, that there is a decline in the average intelligence of the population. B, the families in the upper social strata procreate more abundantly than those in the lower: first consequence, that social descent predominates over social ascent; second consequence, that there is an increase in the average intelligence of the population.

B.—Yes, I see that, but how can the danger be averted?

Decline in the Birthrate among the Upper Social Strata

A.—First of all we have to inquire what accounts for the extraordinarily rapid fall in the birthrate among the families of the upper classes. The most potent causes are certainly economic ; especially the high cost of the education needed to fit children for entering the liberal professions. Parents who wish to give their children a good education restrict the number of their offspring ; and since it is especially among the cultured class that a knowledge of the means for the prevention of conception is the most widely diffused, and since such persons can more readily procure these means and also have more command over their impulses, it is only to be expected that the two-children system or even the one-child system has come to prevail much more widely among such persons. The long period of study requisite to fit any one to enter one of the liberal professions, and the overcrowded state of all intellectual occupations, have as their result that a university professor, for instance, is not as a rule in a position to found a family until he is well on in the thirties. Naturally persons who marry so late will have very few children. Since, moreover, it is especially our most talented and most efficient women whom ambition or economic need impels towards university study and towards liberal professions, those of our girls who have the best hereditary equipment are most apt to renounce a woman's highest calling, that of motherhood—or at any rate such women are not likely to marry young. It therefore behoves the State to do its utmost to facilitate marriage and the upbringing of a large family for persons who, intellectually speaking, form the flower of our population. This may be done, both by far-reaching State endowment of large families, and by strengthening people's sense of responsibility towards the community at large.

Favouring the Procreation of Intelligent Offspring and of Large Families

B.—You are of opinion, then, that the State should provide especially talented young persons who are free from hereditary taint with means for founding a family, and that these State subsidies should increase in proportion to the number of children they have ?

A.—That would certainly be a means for promoting the wide diffusion of a sound hereditary equipment, and for bringing a true aristocracy of birth into existence. But these measures must be extended to

Raising the Intellectual Level

the hereditarily sound large families of all classes. Of course, for ethical reasons, the methods used by breeders of the lower animals cannot be applied to human beings. In the human species the sexual impulse has been sublimated into love ; mutual attraction, elective affinity, is the securest foundation of a happy family life, and must remain the prerequisite to the birth of happy and successful offspring.

Universal Geniuses

B.—If it should really prove possible to pair the children of highly talented families for many generations in succession, we should, theoretically at least, be able to breed universal geniuses.

A.—An increase of the intellectual level, and the production of a larger number of highly talented persons, would not only be possible but probable. You must, however, abandon your hopes of breeding supermen. In one of our earlier evenings, we discussed the fact that the organism has at its disposal only a limited quantity of building materials, to which all the organs put in their claims. A surplus consumed by one part must be taken away from another part, perhaps a more important part. The organism can only remain healthy when a fair balance of allotment is maintained. This applies to the brain no less than to other parts. The modern study of this organ has shown that the grey matter, which is the seat of the higher intellectual processes, contains many hundreds of "centres" differing markedly one from another in structure and function. A very slight spatial restriction of a particular centre involves a lowering of its functional capacity. But a general enlargement of all the centres is rendered impossible by the fact that our brain is enclosed within a rigid bony case, and that we all have to come into the world through the pelvic cavity of the female. Consequently, a simultaneous overdevelopment of all the centres which would be necessary for the production of a universal genius is a utopian fancy. Since only a few of the centres can simultaneously develop to a greater extent without prejudice to the development of other centres which are equally important to life, a truly creative personality can only arise endowed with exceptional advantages in a few directions. A genius can only be a genius in one or two fields.

Restrictions to Mental Development

Size of Skull

B.—Since the size of the skull restricts the size of the brain, and the development of the intellectual faculties depends to a large extent upon the size of the brain, I suppose that intellectuals and the members of liberal professions have in general larger skulls than the manual workers.

A.—Yes, the persons among us who are prominent for their intellectual capacity have not merely larger skulls, but their wives have wider pelves, since the pelvis must keep pace with the skull in its development. A decline in the number of children among the higher classes has, therefore, a dysgenic influence along these lines as well, and leads to an increased proportion of women who have narrow pelves. Bumm states that his experience shows 15 to 20% of all pelves to be too narrow ; and that nearly 5% of German women have pelves so narrow that serious difficulties occur during childbirth. The skilled accoucheur gets to work to help these women through their difficulties, with the result that, as Sellheim points out, the artificial delivery of the children of mothers with narrow pelves tends to

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RAISING THE INTELLECTUAL LEVEL

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brain no less than to other parts. The modern study of this organ has shown that the grey matter, which is the seat of the higher intellectual processes, contains many hundreds of "centres" differing markedly one from another in structure and function. A very slight spatial restriction of a particular centre involves a lowering of its functional capacity. But a general enlargement of all the centres is rendered impossible by the fact that our brain is enclosed within a rigid bony case, and that we all have to come into the world through the pelvic cavity of the female. Consequently, a simultaneous over-development of all the centres which would be necessary for the production of a universal genius is a utopian fancy. Since only a few of the centres can simultaneously develop to a greater extent without prejudice to the development of other centres which are equally important to life, a truly creative personality can only arise endowed with exceptional advantages in a few directions. A genius can only be a genius in one or two fields.

B.—Since the size of the skull restricts the size of the brain, and the development of the intellectual faculties depends to a large extent upon the size of the brain, I suppose that intellectuals and the members of liberal professions have in general larger skulls than the manual workers.

A.—Yes, the persons among us who are prominent for their intellectual capacity have not merely larger skulls, but their wives have wider pelves, since the pelvis must keep pace with the skull in its development. A decline in the number of children among the higher classes has, therefore, a dysgenic influence along these lines as well, and leads to an increased proportion of women who have narrow pelves. Bumm states that his experience shows 15 to 20% of all pelves to be too narrow ; and that nearly 5% of German women have pelves so narrow that serious difficulties occur during childbirth. The skilled accoucheur gets to work to help these women through their difficulties, with the result that, as Sellheim points out, the artificial delivery of the children of mothers with narrow pelves tends to generalise " this notable sign of racial degeneration ". Once more I must be brief and must content myself with giving only a few examples ; but I think I have already said enough to convince you what important pointers biology and the study of the laws of heredity give the eugenist who aims at maintaining the healthiness of the racial stock.

B.—You have not as yet said anything noteworthy about races. To-day so much importance is ascribed to racial purity. Is it true that racial admixture or miscegenation leads to racial deterioration ?

" THOROUGHBREDS " ARE BIOLOGICALLY INFERIOR

A.—Here also we must be cautious in drawing inferences from the experience of breeders, who aim at the intensification of characters outwardly manifest to human beings, but who, thereby, often disturb the vital harmony, the biological excellence of thoroughbred animals, so that these would not be able to maintain themselves in existence without human care. A biological species or race consists of animals or plants whose offspring resemble their parents in all respects save for trifling individual variations. In this sense there are no " races " among civilised men. All the civilised peoples are mixed stocks. For instance, Lenz tells us that all the Germans have " an admixture of Mongolian, that is to say of ' coloured ' blood ". No " pure " race, such as may still be found among primitives, has ever created cultural values. The primitive population of China was composed of Tibetan and Farther Indian tribes, to which contributions from the Manchus and from the Tatars were subsequently superadded. The ancient Egyptians were an African people with a considerable admixture of semitic elements. Hellas was peopled by Indo-Germans of Nordic type who mingled with the indigenous population of the Grecian peninsula. The Romans consisted of Latin, Sardinian, and Etruscan elements in the main, but many other racial stocks were intermingled. The like has been true of the other leading peoples of the world. All the European nations consist of mixed races, varying only in their percentage composition. Thus among Germans, in the northern provinces there predominates the Nordic race, characterised by tall stature, fair hair, and blue eyes ; whereas South Germany is mainly peopled by persons sprung from the dark-haired and dark-eyed Dinaric race. Günther also distinguishes in Germany members of the Falic, Ostic, and Westic races, which, however, are less distinctly marked. Certainly it is beyond dispute that the Nordic race predominates in the higher occupations, and that the Nordic hereditary equipment is an especially good one. But if you wish to study these questions you must refer to special works upon the topic, and I can especially recommend you to the writings of Günther and of Eickstedt. To-morrow, the last day of our vacation, we will devote our evening conversation to considering how the laws of heredity bear upon the validity of the various theories of evolution.

ALL THE CIVILISED NATIONS ARE MIXED STOCKS

THE NORDIC RACE

TWENTY-FIRST EVENING

REVIVAL OF DARWINISM

Non-Inheritable Modifications

B.—During the night I mentally recapitulated the substance of our conversations during the last three weeks, and was amazed to realise how deep an insight biological research has given us into the mechanism of life. I see, likewise, that natural selection, by the elimination of weakly individuals, helps to keep species strong and healthy. Since, however, fluctuating individual variations are not transmitted by inheritance, it seems to me that the theory of natural selection cannot account for the origin of new forms and adaptations. The question how, in the course of the ages, hundreds of thousands of different species of plants and animals have developed out of the simplest living organisms (themselves, perhaps, products of spontaneous generation), remains, to my way of thinking, fundamentally unanswered. Must we, then, renounce the hope of learning how species originated ?

A.—I agree with you that the theory of natural selection fails us, if selection is supposed to work upon individual variations of a superficial kind, not deeply rooted in the germ-plasm. But, as I have already hinted and will now emphatically repeat, in addition to these fluctuating variations there occur variations which are unquestionably inheritable. Nevertheless, over and above selection, other forces must certainly have contributed to bring about organic evolution.

Lamarckism

On a previous evening I gave you a brief account of the theory by which Lamarck endeavoured to account for the development of the various organic types. Characteristic of that theory is the stress laid upon the formative influence which the conditions of existence are supposed to have exercised upon the structure and the outward appearance of organisms. A change in environmental conditions arouses new needs, leading to an increase or diminution or modification in the claims made upon this organ or that, or upon all of them. Since an organ is strengthened by increased use, whereas it is weakened by neglect, with the result that the other organs, in the former case, get less, and, in the latter case, more, of the general supply of materials for building up their structure, a newly-arising need brings with it, to some extent, the possibility for its own satisfaction. Whilst the theory of natural selection ascribes to the organism a purely passive role, the Lamarckians consider that the creative force is actively inherent in the living body. The assumption seems to throw light upon the matter at issue, though it cannot account for the very numerous passive modifications. But the fundamental weakness of Lamarckism lies in its dependence upon the working of a process which is not yet known to occur, namely the inheritance of acquired characters. From the standpoint of pure theory, a good many biologists are inclined flatly to deny the possibility of any such inheritance ; but Plate and others concede the theoretical possibility.

B.—Surely the question can be settled by experiment ?

INHERITANCE OF MUTILATIONS DOES NOT OCCUR

A.—There has been no lack of experiments which might prove the inheritance of acquired characters, did it ever occur ; but clear and convincing proof that such inheritance occurs has not yet been forthcoming. For thousands of years among the Jews, and among many primitives also, circumcision has been practised generation after generation, but no atrophy of the foreskin has ensued. For millenniums, foot-binding has been widely practised by the women of China, but the resulting deformity of the feet is not hereditarily reproduced. As to experiments directly planned to support the Lamarckian view, though there have been plenty of them, they have given no results worth considering. More important have been attempts by modifying the parental environment to produce malformations in the offspring, with a continuation of the investigation by breeding experiments to see whether the changes are hereditarily transmitted. The classical instance is that of numerous researches in which the effects of temperature on butterflies has been studied. Thus, Fischer reared numerous woolly-bear caterpillars (caterpillars of the tiger-moth, Arctia caja) on dead-nettles and dandelion leaves until they entered the chrysalis stage. Some of the pupæ were kept under normal conditions, and developed into normal tiger-moths. From the other chrysalids, which had been intermittently exposed to a temperature of 8° C., there emerged 41 moths which were much darker in tint than ordinary tiger-moths. An exceptionally dark specimen of the males thus modified by the cold was paired with an exceptionally dark female similarly modified. The caterpillars that hatched out of the eggs laid by the latter were reared, and the chrysalids were kept, at the ordinary temperature of the room. Of the 173 resulting moths, most had reverted to the ordinary tint of the ancestral stock, but 17 displayed the same dark colouration as their parents. Similar results were obtained in the course of experiments on eyed hawk-moths and various other species of butterflies and moths, and were widely regarded as furnishing proof that changed environmental conditions can produce variations capable of being transmitted by inheritance.

EFFECTS OF TEMPERATURE ON MOTHS AND BUTTERFLIES

B.—Still, there does not seem to be any warrant for speaking of the inheritance of acquired characters, as far as the results of these experiments are concerned. The cold to which the pupæ were exposed must have acted on the germ-plasm as well as on the body-cells.

Oskar Hertwig

Tower's Experiments on the Colorado Beetle

Changes of Colour in Algæ

A.—That objection was raised in many quarters. But to lend support to the Lamarckian theory of evolution it would suffice to prove that a change in environmental conditions evokes modifications which are transmitted by inheritance, and continue to appear when the original conditions have been restored. If external influences can modify the germ-plasm in such a way that variations persist in the phenotype of the offspring, " inheritance " has taken place. The important point is that the modifications must be durable, so that there is not a reversion to the ancestral type as soon as the old environmental conditions are restored. The customary meaning of the term " inheritance ", writes Oskar Hertwig, " is the transmission to descendants of a possession acquired by the testator. The heritage will not be regarded as genuine or spurious, according as the testator may have acquired it in one way or another." I would go a step farther. Let us suppose that some environmental influence, modifying body-cells and germ-cells, does so in different ways. Let us suppose that in the brood exposed to unusual cold the result upon the body-cells is that in their germ-cells the colour-producing gene has remained unaffected, whereas the cold has modified the gene upon which the size of the wings depends, has modified it in such a way that in the next generation the wings will be smaller than in the ancestral stock. If we go on breeding from this strain under normal temperature conditions, we shall get insects of the customary tint, but with smaller wings than normal. Here, too, there would have been inheritance of an acquired character, but the newly acquired hereditary character " small-winged " would not manifest itself in the phenotype of the parents, and would only disclose itself in the phenotype of the second generation. That is merely a hypothetical instance. In any case the before-mentioned experiments show that changed environmental influences can produce bodily changes which, when the old environment has been restored, continue to appear in part of the offspring. We must not forget, however, that Fischer also practised selection, picking out the extremer types of modification to breed from. Similar results were obtained by Tower's breeding experiments upon the dreaded " potato-bug " or Colorado beetle, Leptinotarsa decemlineata. In this insect, a black colour was produced by a slight increase or lowering of temperature, or by a moderate increase or diminution of the amount of aqueous vapour in the air. When the environmental changes were more extensive, a reduction in the formation of pigment ensued. To some extent these changes were transmissible by inheritance. As Engelmann showed, certain algæ (oscillatorieae), when long exposed to coloured light, assume a complementary colour. If, for instance, we cultivate such algæ for several weeks in a green light, the plants turn red, and remain of this colour when further cultivated in ordinary daylight. Since repeated cell-division takes place, and the daughter-cells are as red as their parents, we can here likewise speak of an acquired change which is hereditarily transmissible.

MOUNTAIN-PINES IN THE PLAINS

B.—It would be interesting to take the seeds of pines and larches from mountain regions, where these trees grow far more slowly and form very thin annual rings, in order to find whether the qualities acquired during many generations at high altitudes would persist in the plains.

A.—Such experiments have been made. Seeds of Alpine varieties were planted near the sea-level, and it was actually found that the trees raised from such seed were distinguished by slow growth and narrow annual rings. Still, it must be remembered that the seeds had themselves been exposed to a mountain climate. Anyhow, to produce new varieties by changed influences, it would not even be necessary that the acquired characters should be inherited by the germ-plasm. If our climate were to become colder, so that, during the chrysalis stage, immature moths and butterflies were (as in Fischer's experiment) exposed to a lower temperature than at present, one may presume that the mature insects would tend to be of a darker colour. Since the offspring of these modified imagos would likewise be exposed to the colder temperature, they would be dark, like their parents (and perhaps even darker than these)—no matter whether the change had become hereditarily fixed or not. Moreover, changed conditions of existence affect, not colour alone, but numerous other characters, such as size, the formation of scales, the growth of hair, etc. If the alteration in the climate were to persist, animals might arise differing so greatly from the ancestral stock that we should be compelled to regard them as new species. The original species would have become extinct. Only if it were possible artificially to reproduce the original environmental conditions, should we be able to determine whether the new characters had become hereditarily fixed. Should seeds of various terrestrial plants be carried by a meteor to some other planet on which their life could be sustained, these plants would, under new conditions of gravity, atmosphere, etc., assume so different a phenotype that to us they would be unrecognisable.

ORGANISMS ARE CONSTRAINED TO BE WHAT THEY ARE

Despite the fixity of hereditary equipment, both animals and plants are in great measure constrained to be what they are, not only (and perhaps not mainly) by the genes handed down to them by their parents, but also by the environmental stimuli that affect them during individual development and during adult life. To express this in

THE PHENOTYPE LESS STABLE THAN THE GENOTYPE

a concise formula, the phenotype is much more modifiable, much more labile, than the genotype.

B.—That is made exceedingly plain by the remarkable forms of the dwarf trees which the Japanese produce by underfeeding. It would seem, then, that there is a variable balance between the phenotype of an organism, on the one hand, and the conditions of existence on the other.

Influences that Act during Embryonic Life

A.—Yes. Above all during embryonic development a change in environmental stimuli evokes corresponding modifications in the organism. The less a living creature is specialised in a particular direction, the less resistance does it offer to change. We see this plainly when we examine the numerous chaotic varieties that appear in the record of the rocks when new species are coming into existence. Only by slow degrees does a classical type crystallise out.

Vanessa Levana

B.—In many butterflies, Vanessa levana, for instance, the imagos that emerge from the chrysalids differ markedly in aspect according to season. Does this difference depend upon the temperature ? The spring butterflies have a general light tint, with map-like markings on the wings. In June, from the eggs laid by these there develops the summer form, which has a basic colour-tone of black, marked with light spots and patches. I believe this phenomenon is known as seasonal dimorphism. Since the pupæ from which the spring form emerges have persisted in the chrysalis stage throughout the winter, one is apt to suppose that the variation of temperature as between winter and summer must account for the dimorphism.

Seasonal Dimorphism

A.—The supposition is confirmed by experiment. The pupæ which, under natural conditions, would develop into the summer form, will, if kept cold, produce spring vanessæ once more ; and, conversely, the eggs, larvæ, and pupæ of the summer form, if kept warmer than usual, will develop into the summer form once more. Probably the different races of many species of butterflies found in the northern, temperate, and torrid zones respectively, are produced only by climatic influences. Eimer already pointed out that our common copper butterfly (Lycaena icarus), whose habitat extends from Lapland to Sicily, has only one generation per year in Lapland, but two generations in Germany. In North Germany these two generations are alike, but in South Germany they differ in appearance. Another of the copper butterflies, Lycaena agrestis, has twofold " seasonal " varieties, the imago exhibiting three distinct forms. Forms A and B alternate in Germany as winter and summer forms respectively. Forms B and C, on the other hand, alternate in Italy as winter and summer forms, respectively. Thus form B is found in both climates ; appearing, however, in Germany as a summer form, and in Italy as a winter form.

The Copper Butterfly

B.—It would be interesting if one could ascertain whether the differences of colour often noticed in butterflies as between males and females can be modified by external influences.

DIFFERENCES OF COLOUR AS BETWEEN MALES AND FEMALES

A.—Researches of the kind have been made. Thus the male brimstone butterfly (Gonepteryx rhamni) is of a bright lemon-yellow, distinguishing it markedly from the whitish-yellow female. When the butterflies are bred indoors at the ordinary temperature of a living-room, this sexual dimorphism disappears.

THE BRIMSTONE BUTTERFLY AND PARNASSIUS APOLLO

B.—Does the male in that case become light-yellow too?

A.—No, the females assume the richer colour-tone of the males. In the handsome Alpine butterfly, Parnassius Apollo, Standfuss was able, by heat, to produce females looking like males, and, by cold, to produce males looking like females.

B.—In view of the notable influence of temperature upon colouration and marking, one's doubts as to whether "protective colouration" and colour-adaptations have really been originated by selection are renewed. It seems more likely that they result from the working of various stimuli.

A.—That may be so, although no satisfactory analysis of the various stimuli has hitherto been possible. Of course other stimuli besides temperature exert a decisive influence on the shape and colour of the organism. We have already considered the atrophy of the eyes that ensues when animals live for many generations in the dark. In certain eyeless species of termite, the fully sexed insects have eyes, which they need and use to good purpose during the nuptial flight. But when, thereafter, the queen termite has been immured in her cell for years, there ensue (as Holmgren showed) marked degenerative processes in her eyes. Experimenting on the cave-olm (proteus), Kammerer was able to show that the absence of the light stimulus was directly responsible for the atrophy of the eyes. He found that when olms were reared in the light, their eyes developed normally. One may presume that these creatures did not adopt cave-life long enough ago for the atrophic process to be irrecoverable. There are, however, various animals adapted to a life in the dark, whose ancestors presumably had eyes, but in which eye rudiments are not even formed during embryonic life. Most biologists take as a matter of course this atrophy of the eyes in parasites, cave-dwellers, and many of the deep-sea fauna; "but herein", insists Plate, "we find one of the most convincing proofs of the inheritance of acquired characters, which is so widely contested and is often declared to be impossible. We can follow the atrophy stage by stage; and since, as a result of it, the eyes become indifferent organs which are neither useful nor

ATROPHY OF THE EYES IN THE QUEEN TERMITE

PLATE'S EXPLANATION

harmful when they have been put out of action by migration into a pitch-dark habitat, we cannot see how the selection of chance minus variations can have brought about the gradual atrophy, inasmuch as the just as frequent plus variations must work in the opposite direction." In Plate's opinion, therefore, the only possible explanation is that the atrophy of the eyes ensuing upon the absence of light must have exercised an inhibitive influence upon the corresponding heredity

Blind Cave-Fish

factors or genes. Popenoe, however, by his researches upon blind cave-fish was led to the opposite conclusion, though these animals have been regarded as classical instances of the inheritance of atrophy due to non-use. In every generation, declared the Lamarckians, the repeated effect of the non-use of the eye was transmitted by inheritance, a cumulative working, thanks to which, in the end, both capacity for vision and eye had disappeared. But in the absence of any known or as yet conceivable physiological mechanism by which such a cumulative effect can be exercised upon the germ-plasm (the bearer and transmitter of the hereditary equipment), Popenoe regards such an assumption as fantastic. In his view, a much more simple and unforced explanation of what happens is possible. " From time to time, in many animals, morbidly altered genes that affect the eyes appear as mutations. If vision is essential to survival, such genes are rapidly eliminated from the stock by the death of their carriers. In cave-dwelling creatures, however, vision has no survival value, so the members of the species in whom defects of the eyes and of vision appear are not eliminated, but reproduce their kind, with the result that visual defects accumulate from generation to generation until, after a sufficient number of generations, the fish have become completely blind. Besides, most caves in which there are underground streams naturally have an inlet or an outlet for the waters. Fishes with good eyes perceive the glimmer of light, and swim out, whereas those with defective vision stay in the cave. That is why, after a while, the underground waters are peopled by fish with atrophied eyes." I myself agree that, in view of the germ-plasm's marked independence of the body-cells, it is hard to conceive of any mechanism whereby influences that modify the body-cells can modify the germ-plasm. Also it is a well-known fact that creatures living perpetually in the dark tend to lose the pigment from the cells in the surface of the body. Wilfer holds that, speaking generally,

Light and Radiation as Factors of Evolution

light and radiation have had much more effect than is commonly supposed upon the evolution of the organismal world. The modifications in plants and animals that have occurred in the course of geological history are usually referred to displacements of land and water, to the coming of the Ice Ages, to the upheaval of mountains, and to similar processes, which rendered new adaptations essential if the organisms opposed to a changing environment were not to die out. But the main evolutionary series displayed to us by the record of the rocks do not coincide with the most extensive geological transformations. We find that almost simultaneously, not merely particular families and orders, but whole classes of the animal world have struck out upon new developmental paths, whereas geological transformations upon the large scale have in most cases been of a fairly local character, and therefore incompetent to affect the entire organismal world at one and the same time in widely separated parts of the globe. Hence Wilfer is of opinion that we must posit a universally effective stimulus to account for changes occurring in organic types all over the world at once. He believes this transformative stimulus to have been a periodic strengthening of the solar radiations, and especially of the ultra-violet rays. His assumption is supported by the researches of Goodspeed, who has been able to show that the genes are influenced by ultra-violet rays, which give rise to sudden inheritable changes in the germ-plasm, to what are called mutations.

Effect of Radiation on Genes

B.—Please tell me what you mean by a mutation.

A.—I will tell you soon. First let us consider somewhat more fully the effects of light and other factors. Plants are influenced by light much more strongly than animals ; for light is not only indispensable to all green plants, but also greatly affects their growth, the formation of their organs, and their whole external appearance.

Black Poplars and Lombardy Poplars

When we enquire as to what can account for the marked difference in aspect between the black poplar (Populus nigra) and the Lombardy poplar (Populus pyramidalis), we are thrust back on the effects of light as explanation. In the black poplar, it is especially the upper side of the branches that is exposed to light, and the leaf-buds can only develop here. On the other hand, in the Lombardy poplar the under side of the branches is illuminated, and the leaves sprout from that side. In the plainest possible way the dependence of shape upon light is seen in the chlorophyll-bearing organs of plants, those upon which the assimilation of carbon from the carbonic acid of the atmosphere depends. You know the Indian-fig, one of the cactaceæ (Opuntia ficus indica) ?

The Indian-Fig

B.—The cactus with the broad, plate-like, thick, fleshy leaves, which is now often grown in pots ?

A.—Yes. But what you speak of as leaves are really segments of the stem. The leaves have become transformed into spines, and the stems have therefore expanded into pseudo-leaves in order to increase the assimilating surface. If we grow an Indian-fig in a dark room, the stem-segments retain the cylindrical shape which corresponds to their primitive function, and never become flattened. In many orchids, the roots contain chlorophyll, and take on the functions of leaves. As long as the roots remain imbedded in the mossy coat of the branches on which these orchids are parasitic, they are cylindrical; but as soon as they emerge into the daylight they assume a flat shape.

B.—Then I suppose it is also ascribable to the effects of light that ivy always thrusts out its clinging roots upon the shadowed side of the tree to which it is attached?

A.—Yes, and the anatomical structure of leaves varies immensely according as they grow in the light or in the dark or in chiaroscuro.

Effects of Gravity

B.—I suppose it would hardly be possible to ascertain whether gravity has any special influence upon growth and development, since on the earth all organisms are equally and permanently exposed to the force of gravitation?

A.—No, that difficulty can be eluded by the use of an instrument known as a clinostat, a turntable with a horizontal axis kept in slow rotation by a clockwork mechanism. Anything attached to such a turntable is practically withdrawn from the influence of gravitation, since the pull of the earth is exerted upon it in a continually changing direction. If, for instance, a creeper is bound to such a turntable, the twisting movement of its stem ceases, the younger portions straighten themselves out, and the whole plant becomes extended. Here is another instance. By the use of a clinostat, Massart withdrew from the action of gravity a tropical plant, Alloplectus sanguinea, which under normal conditions is characterised by asymmetrical leaves. No change was at first apparent. Even the leaves that were in course of formation remained asymmetrical. But when alloplectus seeds were allowed to germinate upon the clinostat, they developed symmetrical leaves. Here you have additional proof of the different degree to which organisms react to stimuli in various phases of their existence.

Germination upon the Clinostat

B.—Can the influence of gravity upon developing organisms be detected in the case of animals as well as plants?

Development of a Water-Beetle

A.—In this connexion a very interesting observation was made by Megusar upon the eggs of Hydrophylus aterimus, a water-beetle which constructs boat-shaped cocoons that float upon the water. The elongated eggs in the interior of this cocoon are placed side by side with their long axes vertically disposed, and the cephalic rudiment of the embryo develops at the lower, pointed end of the egg. This head-downward position is maintained throughout the period of embryonic development. If the cocoon be turned upside-down, so that the cephalic rudiment points upward, the developmental process slackens, the larvæ emerge from the eggs several days later than usual, and are also dwarfed. They have a more stocky shape, and their movements are more sluggish, than when they have grown head downwards in the usual way. They are unable to seize their prey, and perish within a few days after hatching.

MODIFICATIONS CAUSED BY CHANGES OF DIET

B.—Observations on tadpoles have shown that change of diet can modify them in various ways. It is also a remarkable fact that when cayenne pepper is mixed with the food of canaries, the birds assume a reddish colour ; and that feeding with hempseed gives the male bullfinch a blackish plumage. I have read in books of travel that the indigenes of the basin of the Amazon give the parrots of the district (a green bird known as Amazona amazonica) the fat of certain sheat-fish to eat, whereupon the birds' plumage is interspersed with bright-red and bright-golden feathers.

ARTEMIA AND BRANCHIPPUS

A.—You already know how far-reaching an influence the salts and other substances contained in the soil have upon the growth of plants. Such knowledge supplies the principles for the use of artificial manures. A maize plant nourished upon a culture solution to which magnesium sulphite has been added, develops so peculiar an inflorescence that no botanist who saw it for the first time without knowing the circumstances would assign it to the maize genus. No less striking are the effects of chemical stimuli upon the appearance of many animals. In the brackish lagoons of Istria lives a small crustacean, Artemia salina, which is mainly distinguished from its fresh-water cousin branchippus by having fewer abdominal segments. By gradually reducing the salt-content of the water, Schmankewitsch was able to modify the appearance of artemia until it closely resembled branchippus ; and, on the other hand, by increasing the salt-content of the water, Artemia salina was made to resemble Artemia milhauseni, which has a short tail-flapper devoid of bristles. Schmankewitsch regarded this as an unexceptionable instance of the inheritance of somatically acquired characters. But according to recent investigations of Hartmann and Abonys, we have not to do here " with the production of new races, varieties, or species ; for the species remains always the same, but assumes different forms in accordance with the varying salt-content of the water in which it is reared. Not only does the form vary with the concentration of the solution, but also the mode of reproduction, for in weak solutions live young are born, whereas in strong solutions thick-shelled eggs which do not hatch out for some time are laid ". But if the offspring of the modified types are reared once more in the brackish water which was the customary habitat of their ancestors, they resume the characters of Artemia salina. The newly acquired characters have, therefore, not become hereditarily stable. So far we must agree with Hartmann. But in such experiments the organisms are exposed to the transformative influences for a comparatively short time and only for a few generations, whereas geological time is reckoned by æons and lasts for countless generations. Perhaps that is why, though the transmutable phenotype can easily be changed by a change in environmental conditions, no effect is produced upon the genotype, which is far more conservative. Anyhow, what I chiefly wanted to show you was

MODIFICATION AND ADAPTATION

what extensive modifications in organisation and the life-cycle can be produced by very slight changes in the conditions of existence. Plate insists that it is : " a general law that many characteristics are first evoked in every individual member of a species by environmental stimuli and by the mode of life, and that subsequently, in the course of many generations, they are adopted into the hereditary mechanism. This implies that the somations (bodily changes) slowly but effectively transform the germ-plasm ". The words are illuminating, but the statement cannot as yet be regarded as proved.

B.—Are these modifications induced by changes in environmental conditions always to be looked upon as adaptations ? In other words, does the organism always react to a new stimulus by way of an appropriate change ?

VARIOUS EFFECTS OF CHANGES IN STIMULUS

A.—No, the changes are not at first appropriate or purposive. When a bullfinch fed on hempseed turns black or an oyster removed from the North Sea to the Mediterranean acquires a gaily ornamented shell and throws out long spines, or a sea-urchin's egg kept in water containing only an inadequate supply of lime develops into a larva which has no supporting skeleton, we cannot see anything purposeful in the modifications, many of which unquestionably impair the vital powers. The modifications that result from a change in environmental influences may be useful, indifferent, or noxious.

B.—What valuable inferences can we draw from these facts ?

A.—That every organism is in a condition of unstable equilibrium vis-à-vis its environment. If the balance is upset by a change in external conditions, the organism may perish, or it may undergo modification until a new equilibrium is achieved. This new equilibrium is not necessarily an improvement upon the old, but implies a more or less satisfactory coming to terms with the inevitable. Of course the survival of the new type depends upon how satisfactory the accommodation is. If the acquired changes are useful or indifferent, then the individual will presumably survive ; but if they are harmful, then natural selection will soon weed out the defectives. For the rest, a change in the milieu does not act upon all species in the same way. Stimuli which may speedily produce a marked alteration in one species, may have no more effect on another species than water on a duck's back. In our own time, nature has been making a large-scale experiment upon adaptation to changed conditions.

THE CORYNID

Down to the middle of the eighteenth century, the delicately branched little trees of the hydrozoon corynid were known only as inhabitants of the brackish waters in the estuaries of European and North American rivers. Then the polys began to make their way upstream, and are now met with as denizens of numerous rivers and lakes. This is an instructive, though rare, instance of the speedy change of a sea-dweller into an inhabitant of fresh water.

B.—Surely, however, the hybridisation of different species has led to the formation of new species—or am I mistaken ?

IMPORTANCE OF CROSSING

A.—Your question opens up an interesting point. For thousands of years the mule has been known as a hybrid between the donkey and the horse. There are two kinds of mules according as the father is a jackass and the mother a mare, or the father a stallion and the mother a she-ass. But such hybridisations are not, as far as our experience goes, an important factor in the origination of species.

INVALIDITY OF HYBRIDS

Apart from the fact that, under natural conditions, the sexual instinct of the animal concerned prevents hybridisation, such hybrids are either infertile, or at any rate manifest a greatly lowered fertility. Of course we do know of hybrids which are capable of reproducing their kind. For instance, the hybrid that springs from a union of the rabbit and the hare remains fertile for generations ; and hybrids of domesticated goats and the Alpine steenbok, as well as those produced by various species of butterflies which reproduce themselves for two or three generations. The investigations of Poll have shown, however, that in nearly all hybrids where the specific differences are as marked as in those mentioned, the development of the reproductive cells is seriously impaired. When the species are closely related, ripe ova and spermatozoa are still formed, although in reduced numbers ; but the more widely the parent species diverge, the more is there a tendency for the development of the reproductive cells to be arrested at an early stage. In fact, this gives us a means of determining the degree of phylogenetic kinship between various species capable of coupling one with another. When the phylogenetic kinship is remote, hybridisation is impossible because the alien albumin of the spermatozoon has a destructive effect upon the albumin of the ovum, and conversely. Hybridisation has perhaps played a more important part in the vegetable world. For instance, we are acquainted with fruitful hybrids formed by the crossing of different races of wheat, which manifest a remarkable variability and multiformity from the second generation onward. Individuals arise possessing entirely new heritable characters. Still, it would be a mistake to ascribe much importance to hybridisation as a species-producing factor even in the case of plants.

B.—If, however, natural selection has not played a considerably greater part in promoting the origin of species than it would appear to have played according to your previous expositions, we seem to have come to something very like a deadlock as regards our problem.

MUTATIONS AND SPORTS

A.—You do not need to take so pessimistic a view, for we have not yet considered the most important factor in bringing about the transformation of species. As I have already pointed out, side by side with the non-inheritable fluctuating individual variations, there occur the sudden and considerable variations known as mutations—spontaneous changes of one or more genes, which are inheritable from the outset. Sometimes the whole character of a living organism is more or less markedly modified from the first by such a mutation. Of course so acute an observer as Darwin did not fail to notice the occasional appearance of such "single" variations or "sports"; but he was not inclined to regard them as of importance in accounting for the origin of species when compared with the slight, gradual, and fluctuating variations to which he paid special attention. Long before his time, it had been noticed that among normally leaved plants such as the hornbeam, the oak, and the celandine, forms with fissured leaves would suddenly appear. The earliest report relating to this matter dates from the year 1590, and was made by an apothecary named Sprenger of Heidelberg, who, among the celandines (Chelidonium imaius) in his garden suddenly discovered one with fissured leaves, which, being used to breed from, bred a true succession of fissured-leaved plants. A yet more remarkable case occurred in the animal kingdom in the year 1791. In a flock of sheep in Massachusetts, among a number of normal sheep, one was born with an exceptionally long back and short fore-legs. Although this animal's appearance was so unnatural, it was crossed with a normal sheep in the hope of obtaining a race which would be unable to jump the fences separating the farmers' fields. In the next generation, through the working of the Mendelian law which was still unknown, the offspring were some of them short-legged and some of them normal. When two of the short-legged shape were paired, the new character proved to be hereditarily stable. In other words, the new gene had been segregated. It was bred for many generations, but in course of time these Ancon sheep were replaced by the more lucrative merinos. To the same category belong black-shouldered peacocks, one-hoofed swine, animals with curly hair sprung from a straight-haired race, those with an exceptionally large number of cervical vertebræ, albinos or melanotic species, hornless cattle in a horned herd, and many similar cases. The dachshund, which was bred already in ancient Egypt, was probably a mutation from the greyhound. Much more importance than can be ascribed to these very marked sports, differing so greatly from the genotype and the phenotype, must be given to the slight mutations which, since the first observations of Hugo de Vries, have been noticed more and more abundantly, and have been regarded as the source of new species.

Ancon Sheep

De Vries

The Basis of the Theory of Mutations

The classical object on which de Vries's investigations were carried out was the evening primrose (Œnothera lamarckiana), which produces fine yellow flowers, and is especially prone to grow on railway embankments. As long ago as the 'eighties of the last century, in the neighbourhood of Amsterdam, de Vries was on the look-out for a plant showing exceptional variability, and was lucky enough to find what he wanted in the evening primrose which had established itself by hundreds in a potato-patch left fallow near Hilbersum. Among the specimens growing there, there were two forms diverging so greatly from one another that they might be regarded as new species. They were subsequently styled Œnothera brevistylis and Œnothera lævifolia, and bred true, both of them. In 1886, de Vries transplanted a number of roots and seeds from the potato-patch to his experimental garden in Amsterdam. From the seeds of these first examples, he raised, in the course of several generations, in addition to normal plants, seven new species appearing by mutation, five of them proving hereditarily stable on self-fertilisation. The theory of mutations grounded by de Vries upon his experiences with the evening primrose has proved extremely fruitful. We know to-day that, through the sudden modification of particular genes, new hereditarily stable qualities may arise ; and it is plain that this process prevails widely throughout the animal and vegetable kingdoms. It is also clear that a change in the environmental conditions favours the appearance of mutations. Still more important is it that, by the working

Artificially produced Mutations

of external influences, for instance by exposing the older larvæ of the fruit-fly to higher temperatures than usual, we can not only produce mutations, but can also achieve an accumulative development of these variations, which increase by successive stages from generation to generation. What Goldschmidt and Jollas effected by changes of temperature can probably be achieved also by other changes of stimuli. To-day there are many reasons to suppose that a persistent working of environmental changes, such as have frequently occurred during earlier phases in the history of the world, mutations that were at first indeterminate, have been given a definite trend. If this be so, however, then, by the accumulation of such tendentious mutations, hereditarily fixed deviations must arise, and these will have a positive or negative selectional value. This would provide the fulcrum upon which the lever of natural selection could work by means of the struggle for existence. Thus the theory of mutations and the Mendelian laws of heredity have provided a powerful support to Darwin's ideas.

Œnothera, a Permanent Hybrid

Now I come to something very strange. According to recent investigations made by Renner and others, it seems clear that Hugo de Vries founded his theory of mutations upon the study of an object which we have little or no right to regard as a true mutation. All the appearances tend to show that Œnothera lamarckiana is a permanent hybrid, in whose cells two different reduced (haploid) chromosomes, those of Œnothera velans and Œnothera gaudens, have become united, without, in general, any exchange of factors taking place between the two. This signifies that Œnothera lamarckiana always forms nothing but pure male and pure female velans and pure female and pure male gaudens reproductive cells. Only the fertilisation of a gaudens ovum with a velans pollen grain or of a velans ovum with a gaudens pollen grain—that is to say a heterozygotic union—produces viable Œnothera lamarckiana offspring. If, in exceptional instances, however, there should occur an exchange of genes between the velans and the gaudens chromosomes, then these new combinations of heredity factors manifest themselves in the appearance of mutations. What happens, then, is not a real mutation of the genes of Œnothera lamarckiana but a new combination or new combinations resulting from hybridisation. You see from this that an investigator can be led to form sound hypotheses by proceeding along the wrong road, by the use of an unsuitable object. The researches of many investigators upon the fire-fly and upon numerous other organisms in which genuine mutations occur have shown beyond question that de Vries's theory, however erroneously grounded, is substantially sound.

Co-operation of Various Factors of Evolution

If, then, we survey the results at which we have arrived in these long evening talks, we are forced to admit that the theory of natural selection cannot alone account for the origin of the greatly diversified types presented to us in organic nature ; and that all the theories hitherto formulated can account, in each case, only for a part of the phenomena while leaving others unexplained. One general result, however, we have achieved. We can no longer speak of " either the theory of natural selection, or the Lamarckian theory, or the theory of mutation " ! The forces which these various hypotheses concerning organic evolution summarise are not mutually exclusive. On the contrary, we may assume that the natural selection of the variations of the genes produced by mutation, the direct influence of environmental changes, and other forces (still unknown to us, but not therefore beyond reach of discovery) have co-operated and continue to co-operate in bringing about the evolution of the organic world.

B.—After all our discussions, I find it very difficult to understand why the schools and the churches are still opposed to the doctrine of descent, above all when it is applied to the human race. It seems to me that this strict reign of law in the realm of nature can only arouse in our minds a sense of profound veneration and humility towards the Creator.

A.—That is my standpoint also. I think that the objections to which you refer are an evil legacy, are a result of the one-sided and unphilosophical disputatious attitude of those strict monists, who wanted to use the theory of evolution as a weapon against the churches and the creeds, against a belief in God, and who proclaimed the unfreedom of the human will. Since modern physics has shown that even the apparently omnipotent law of cause and effect has no more than a restricted value, the problem of the freedom of the will has been raised to a new level. The freedom of the will manifests itself most clearly in moral purpose, in the way in which we will and act in accordance with moral laws. The law of causality is valid only in a restricted domain of the human psyche. Let me conclude, therefore, by quoting Kant's fine saying : " Two things fill the mind with ever-renewed and increasing wonder and veneration, the oftener and more persistently we reflect upon them : the starry heavens above me and the moral law within me."

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